

DEVELOPMENT OF A CONCEPT WHEELCHAIR FOR THE ELDERLY

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DEVELOPMENT OF A CONCEPT WHEELCHAIR FOR THE ELDERLY

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SUMMARY

Most age-related disabilities are related to mobility. Generally, movement becomes more difficult as we age. As our ability to walk and stand safely begins to decline, many of us will discover that a wheelchair is our best option for safe and independent mobility as we age in place and later enter the continuum of care.

Though a range of wheelchairs exist to enable and address the functional needs of moderate to extremely active individuals of differing abilities, there has been little or no investigation into developing a wheelchair to meet the specific ergonomic, mobility, and seating needs of elders.

This thesis describes the characteristics of the currently growing elder population in the US and world; the current state of wheelchair technology for elders; the greatest needs for improvement in wheelchairs for the elderly; the goals and results of the research and studies that our team conducted with elders and care staff; and how this information was used to the design of a wheelchair concept that improves elder mobility.

CHAPTER 1: INTRODUCTION:

As the aging-in-place trend grows, more and more seniors are exhibiting a desire to live independently at home or to move into housing that can meet their needs for as long as possible. Governments agree with this stance because they see that providing care within the community and home instead of prematurely introducing elders into a continuum of care is less expensive and can provide a better quality of life. As the trend to avoid unnecessary institutionalized care grows, the need for assistive technology has increased. "Assistive devices are essential to maintaining sufficient independence and to reducing the physical burden on familial caregivers if the community alternative is to be workable" (Fernie, 1997).

Most age-related disabilities are related to mobility. Generally, movement becomes more difficult as we age. As our ability to walk and stand safely begins to decline, many of us will discover that a wheelchair is our best option for safe and independent mobility as we age in place and later enter the continuum of care.

Problem Statement

Though a range of wheelchairs exist to enable and address the functional needs of moderate to extremely active individuals of differing abilities, there has been little or no investigation into developing a wheelchair to meet the specific ergonomic, mobility, and seating needs of elders.

This thesis describes the characteristics of the currently growing elder population in the US and world; the current state of wheelchair technology for elders; the greatest needs for improvement in wheelchairs for the elderly; the goals and results of the research and studies that our team conducted with elders and care staff; and how this information was used in the design of a wheelchair concept that improves elder mobility, a key indicator of quality of life.

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CHAPTER 2: BACKGROUND

Background

Elders who use wheelchairs for mobility have some unique needs that reflect their functional status, the environment of use, and reimbursement policy. Although the majority of elders in residential care environments use wheelchairs, very little assessment of their needs has been done in conjunction with facility needs. Subsequently, little attention to these needs have been incorporated into the design of mobility devices and products.

In order to create better wheelchairs for the elderly, a comprehensive assessment of wheelchair use by elders was necessary. Design improvements that increase safety, improve function and posture, minimize skin problems, and maximize caregiver utilization needed to be conducted based on a thorough examination of the particular needs of residential wheelchair users, facility staff, and facility administration at NHs (or nursing homes) and ALFs (assisted living facilities) (Bernard, R., Anderson, J. and Taylor, J. 2004). Just such a study was performed via a collaborative effort of the Center for Assistive Technology and Environmental Access (CATEA) at Georgia Tech and Emory University. It was internally code-named R2b.

R2b

The specific aims of project R2b were to: 1) further investigate the wheelchair needs of elder users and the families of elders who live in NHs and ALFs. ; 2) assess the needs of direct care staff in NHs and ALFs; 3) assess the needs of administrators (who are often responsible for the purchase of these chairs); and 4) develop design criteria to be used in the development of a new wheelchair for frail elders. (Bernard, R., Anderson, J. and Taylor, J. 2004).

The investigators selected the different stakeholder groups because of their interaction with elder users or their influence on the use of specific devices. These groups included: elderly wheelchair users, primary caregivers, nursing staff, therapists, wheelchair maintenance specialists, and nursing home administrators. Qualitative and quantitative data were collected from each group of stakeholders at three nursing homes, three assisted living facilities, and various nursing home conferences. The stakeholder data was analyzed and synthesized to determine commonalities and differences with respect to the elder wheelchair user.

The stakeholders participated in focus groups and were queried on the following issues:

1) Wheelchair and cushion use, including sitting duration during the day, use of cushion, and type of cushion; 2) Propulsion, including independent or dependent propulsion, methods of propulsion, pain associated with propulsion, and difficulties experienced during propulsion; 3) Safety, including transfers to and from the wheelchair, wheel locks, footrests, unsafe use of the wheelchair as a walker; 4) Storage of the wheelchair, including in the room and traveling storage; 5) Environmental barriers, including flooring, thresholds, and doorways; 6) Suggested improvements; 7) Procurement, ownership, and maintenance.

The surveys were given to nursing home administrators and therapists and were focused more on the procurement and reason for purchasing certain types of wheelchairs. The investigators found it critical to understand the purchasing practices of the nursing home administrators, how much they spend annually on new wheelchairs, and the safety concerns regarding elderly wheelchair use in their facilities.

As mentioned previously, the main purpose for R2b was to find design implications that could be used to develop a better wheelchair for elders. These implications fell into the following categories: 1) Wheelchair Use and Seating; 2) Methods of Propulsion; 3) Safety Concerns; 4) Storage Issues;

5) Environmental Barriers; 6) Maintenance; 7) Procurement; and 8) Purchasing.

Wheelchair Use and Seating

Based on the results from the R2b study, nursing home (NH) residents reported sitting in their wheelchairs approximately 2-17 hours per day with an average of 8 hours per day. According to focus group responses, wheelchair use is essential for participation in NH activities. Many NH residents, (24%) reported that they used a cushion, most of which were makeshift cushions made from pillows or egg crate foam. NH residents complained that these makeshift cushions did not fit the wheelchair, were not thick enough, or caused users to slide out of their chair.

Assisted Living Facility (ALF) residents reported that they used their wheelchair for approximately 1 to 10 hours per day, approximately 50% less than NH residents. ALF staff reported that very few residents depend on a wheelchair for their mobility needs. The average time of use was 4 hours per day, mainly to go to the dining room for meals. Most residents did not transfer out of their wheelchair when eating their meals. If an ALF resident left the facility they would typically transfer out of their wheelchair and sit in the car or van seat during the trip and immediately transfer back into their wheelchair once they reached their destination.

The depot wheelchairs used by most elders features seating consisting of a heat stamped vinyl sling seat and back. This is a poor support surface for long term sitting. Vinyl's lack of durability and breathability does not promote proper postural support, tissue integrity, digestion, respiration, and ease of communication. Because these chairs were only designed for short term transport, and foldability, they lack crucial seating features necessary for long term comfort, namely a solid seat insert and wheelchair cushion.

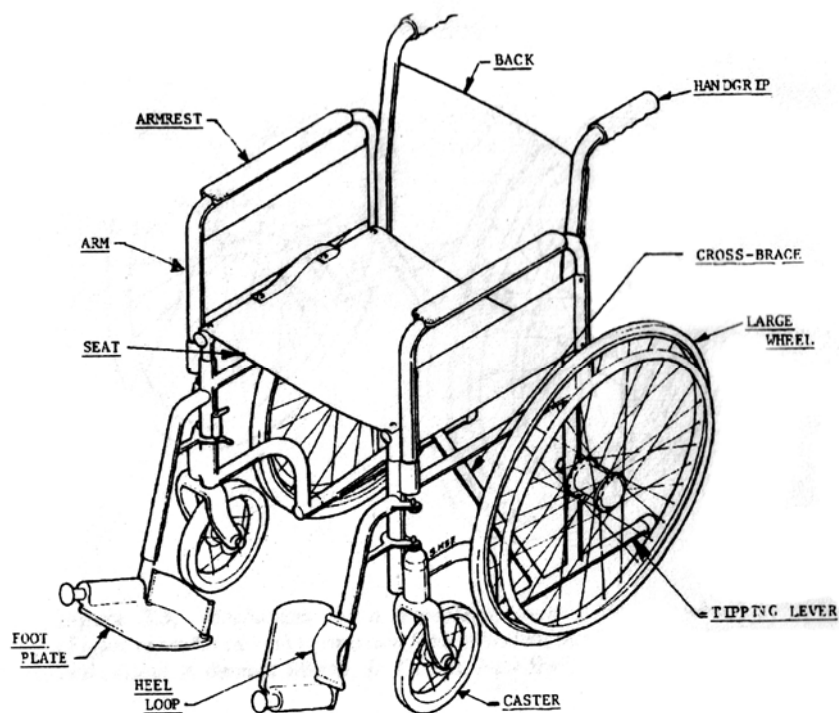


Fig 1. A typical Depot Wheelchair (from Wilson, A. (1992) Wheelchairs: A Prescription Guide. Demos. New York. NY.)

ALF residents did not use a cushion unless it was supplied with the wheelchair. Among residents that did use cushions, most complained (72%) that the cushions were difficult to use and did not stay in place during use. Cushion use is very sporadic among ALF residents. Staff suggested that cushions should be rented or purchased with the wheelchair to ensure proper cushion selection and fit. Staff wanted cushions that were easy to clean and dried quickly or that had removable covers that could easily be washed or replaced.

Implication: A wheelchair that provides low maintenance seating with proper postural and tissue support, pressure relief is essential for the long-durations of sitting encountered by elder wheelchair users.

Propulsion Methods

The investigators asked focus group participants to discuss how they propel their wheelchairs. The majority of nursing home residents preferred to push their wheelchair using their hands and feet together (combination propulsion) or their feet only. Residents reported they used both their arms and legs to propel because their legs were stronger than their arms alone. Pushing with their legs has both advantages and disadvantages. When pushing with their feet, residents reported that they were able to protect their hands and fingers from injury due to narrow door clearance but that they occasionally injured their legs and feet on the front casters when

turning or backing up. Pushing the wheelchair with their feet alone allowed residents to use their hands and arms to guide their wheelchair and hold and carry objects when moving.

In assisted living facilities, wheelchair users must be able to use their wheelchair independently with only minor assistance from staff. About half, 46%, of the ALF residents reported pushing their wheelchair with both their hands and feet. The second most common method of propulsion was using their feet only, representing 31% of the users. The foot rests had been removed for those using their feet to propel, making this an easier propulsion method for ALF residents than for NH residents.

Implications: *A wheelchair that eases combination and foot propulsion stands to aid in independent mobility. The legs and feet of elders need a means of isolation from contact with casters during propulsion to reduce injury.*

Safety Concerns

In nursing homes, resident safety was of great concern. For example, when transferring in or out of a wheelchair, a resident typically stands up, pivots, turns, and sits. During transfers, it is natural for the residents to hold the wheelchair armrest to steady themselves during transfers. But, due to

poor adjustment, poor maintenance or user error, the wheel locks (i.e., brakes) were not engaged, causing the resident to lose balance and fall. Most residents reported that they would feel much safer if the wheel locks were easier to engage and if the footrests could be moved completely out of the way during transfers. Both NH residents and staff reported that footrests contribute to falls and injuries. This is due to the resident tripping or stepping on them and/or others walking by the wheelchair with the footrests opened.

For ALF residents, their greatest safety concern was wheelchair stability during sit-to-stand transfers between the bed and the wheelchair or from the wheelchair to another seat. Many users had difficulty using the wheel locks. They wanted wheel locks that were easier to engage and kept the wheelchair from rolling. They also noted that footrests were a nuisance because they were constantly in the way when the user was trying to move closer to a table or trying to stand up.

ALF staff reported that resident safety might be improved with several wheelchair features. They suggested that the user should be able to push a button to activate a mechanism that would assist the resident in standing. The staff also wanted the user to be able to adjust the seat height to allow for their specific functional need. Wheel locks that could

be activated automatically as the user stands or by the push of a button were also suggested by the ALF staff.

As a whole, most of the stakeholders wanted better wheel locks. The usefulness of brakes that automatically engage when the user shifts their weight to reach for an object or begins to stand up was also discussed. Participants wanted footplates and leg rests that have a smaller profile, were contoured, covered in anti-slip material, and that retract, but do not come off, the chair. Adjustable leg rests, particularly those that could be elevated, were also discussed. These features would help prevent falls and injuries.

Implications: *Wheelchair features such as easy-to-use wheel locks, swingaway footrests, and transfer aids are crucial to elder safety when moving in and out of a wheelchair.*

Storage Issues

In nursing homes, space is limited. In many cases there are two residents living in one small room. In order for the wheelchair to fit in the room, the nurse may have to fold the wheelchair for storage next to the bed. In other situations, for more active residents, the nurse might leave the chair open so the resident can independently get into the chair. Whether the

wheelchair is folded or left open, the nursing home staff said they needed the option of a foldable wheelchair, primarily due to space considerations.

ALF staff needed a wheelchair that would fold to facilitate storage and transportation. A wheelchair that folds for easy transport helps improve the resident's activity level and participation in events outside the facility. Conversely, a wheelchair that is difficult for staff, family, and friends to fold for transport may potentially influence how often the resident is invited out on excursions. Wheelchairs for residents in assisted living facilities should have reduced overall weight and a collapsible design that does not require component removal.

Implication: A wheelchair with the ability to fold makes it easier to store and transport, easing care staff duties and allows elders to have greater frequency of experiences outside a NH or ALF facility.

Environmental Barriers

Nursing home residents reported that narrow doorways are the most challenging environmental barriers they encounter. Narrow doorways are often coupled with high door thresholds, which increase the opportunity for injury to fingers, arms, elbows, and feet. Narrow doorways also restrict access to that space. Floor coverings were the second most challenging

barrier. NH residents described the difficulties of pushing on carpet. The third most common environmental problem is the small room size, which is especially problematic when two residents, both using wheelchairs, share the same room. Assisted living facilities typically have a broad range of resident spaces and a variety of floor coverings that may present a barrier to wheelchair use. While resident rooms are larger than rooms in nursing homes, residents using wheelchairs must often contend with different types of flooring, thresholds, and narrow doorways. Residents reported that narrow bathroom doors are common in assisted living facilities.

Implications: *A wheelchair that can ease passage through narrow doorways, over obstacles, and easily transition from one surface to another will likely improve elder mobility and reduce injury.*

Maintenance

Staff reported spending a considerable amount of time searching for wheelchair components. One of the biggest complaints from the nursing staff was the loss of footrests. Since so many elder wheelchair users use their feet to assist with propulsion, the footrests were removed and stored in a closet. It was noted that finding the right footrest for a wheelchair was usually impossible when a resident needed a footrest reattached or

when another resident needs to use the chair. This required the purchase of new footrests for the chair (adding to the facility's costs). Staff suggested that a wheelchair with footrests that could not be removed but that could be stored out of the way when not needed would be especially helpful.

Implications: *Wheelchairs with captive swingaway footrests stand to provide support for elders' limbs when needed and prevent the frustration of wheelchair part loss.*

Nursing home staff also asked for a wheelchair that could be easily adjusted and maintained by staff. Maintenance staff expressed concern over damage done to chairs while cleaning and repairing them. At some nursing homes, the chairs were power washed, causing damage to the frame and seat. At other facilities, housekeeping wiped chairs approximately once per month. Common repairs to wheelchairs included replacing seats, footrests, armrests, wheels, wheel locks, tires, and casters. Making these repairs can be a labor intensive activity, reducing time spent on other responsibilities at the facility.

Implication: *An easy-to-clean, low maintenance wheelchair that reduces care staff burden is essential to maintaining elder safety.*

Procurement

Assisted living facilities are not required to purchase wheelchairs for residents, although some facilities maintain several wheelchairs for temporary use. Many ALF residents reported that they either use personal funds and/or insurance (including Medicare) to cover the cost of the purchase or long-term rental. The three main methods of obtaining wheelchairs were: 1) Medicare or Medicaid, 2) Rental through a local durable medical equipment vendor, or 3) A family member or friend gives them a wheelchair that had previously been used by a member of their family.

Fifteen nursing home administrators responded to the survey and participated in a follow-up group interview. Over half of the respondents (54%) had 61 or more wheelchairs in their nursing home. Table 1 identifies the respondents' wheelchair types in the nursing home; Twenty-seven percent had more than 81 wheelchairs. The "standard adult" wheelchair was the most common type followed, by the "large adult" type, the "hemi-height," and the "recliner." "Narrow adult" and "motorized" wheelchairs were less common in the facilities.

Table 1. Common wheelchair types in Nursing homes

Wheelchair type	Number of Wheelchairs in use					Total
	None	1	2	3 or more	N/A	
Standard Adult	0.0%	0.0%	0.0%	86.7%	13.3% (2)	100% (15)
Narrow Adult	46.7% (7)	26.7% (4)	13.3% (2)	0.0%	13.3% (2)	100% (15)
Hemi-Height	20.0% (3)	13.3% (2)	26.7% (4)	26.7% (4)	13.3% (2)	100% (15)
Recliner	26.7% (4)	20% (3)	13.3% (2)	26.7% (4)	13.3% (2)	100% (15)
Large Adult	0.0%	20% (3)	13.3% (2)	53.3% (8)	13.3% (2)	100% (15)
Motorized	53.3% (8)	13.3% (2)	13.3% (2)	6.7% (1)	13.3% (2)	100% (15)
Other	None	0.0%	0.0%	13.3% (2)	13.3% (2)	100% (15)

(Bernard et. al. 2004)

Two-thirds of administrators (67%) reported that they purchased between 21 and 80 new wheelchairs each year for their facility. While 27% of respondents spent less than \$1000 annually on new wheelchair purchases, it is interesting to note that 13% said they spend more than \$4000 annually. Almost half (47%) reported spending less than \$1000 annually for the purchase of specialized seating products like wheelchair cushions, although it should be noted that 26% say they spent in excess of \$2000 annually for these items.

Nursing home administrators reported that they usually spend between \$100 and \$200 per institution when purchasing a wheelchair. Administrators preferred not to spend more than \$250 but were willing to

spend about \$400 per chair if the chair included a five year warranty, had interchangeable parts, included a cushion, provided adjustability, and had quality wheel locks.

A majority (60%) of respondents purchased wheelchairs without the assistance of their corporate office. All respondents (100%) indicated that “clinical needs of residents” had a “very strong influence” on their decision to buy, while a majority of respondents (93%) indicated that “resident safety” was a “very strong influence.” Price was a “significant influence” for over half (53%) and was more likely to be an important factor than “brand preference or “vendor relationship.” Decisions made at the corporate office were unlikely to influence respondents’ buying decisions, but administrators indicated that they often confer with a nurse or therapist during the procurement process.

Implication: *Reliability, adjustability, safety, and moderate cost are crucial for enabling elder mobility in NHs and ALFs.*

R2b was an important first step in better understanding the propulsion habits and needs of the elder wheelchair population. The investigators found that approximately 70% of all elder users used their legs either as their main method of propulsion or in combination with their arms. The

elders in this study wheelchairs that have been designed for arm propellers. -Why is this? The discovery that many of the residents spent in excess of 8-10 hours a day in their wheelchair stressed the need for proper seating. Also, inquiries into the amount of money administrators are willing to pay for wheelchairs established a baseline cost for a new elder wheelchair. This study laid foundational design criteria and exposed the opportunities for exploring new ways of looking at elder mobility as preparation for the development of a new wheelchair for elders in Project D2.

D2

Phase D2 is the internal project designation at CATEA for the development of a wheelchair for elders. It builds upon the results of the needs assessments studies performed during the R2b research. The objectives of this project involve designing manual wheelchair technology that can meet the unique needs of elder users across the continuum of residential environments while addressing the needs of family, caregivers and facility staff. (Bernard, R., Shotwell, M. and Taylor J. 2004.)

I joined the design team at the beginning of Phase D2. The following pages illustrate the process has enabled us to meet the interlinked needs

of these users and create a better designed tool to extend elder mobility and independence.

CHAPTER 2: LITERATURE REVIEW

The Graying of America

In the United States, improvements in health care have resulted in increased life expectancy and fostered the increase of the geriatric population over the past century. More than ever before, Americans are living longer. Life expectancies at both age 65 and age 85 have increased. Thanks to medical advancements, individuals who reach age 65 are living an average of 18 more years, over 6 years longer than someone age 65 in 1900. People who survive to age 85 today have a life expectancy of about 7 years for women and 6 years for men (NCHS, 2004).

There are over 34,991,753 people aged 65 and over in this country. This represents a 12.0% increase in this segment of the population since 1990. Data from this census also shows that 4.5 percent of the US Population age 65 and over live in nursing homes. This means that over 1.5 million seniors have entered the continuum of care (Gist and Hetzel 2004.). Many of those living in nursing homes use wheelchairs as a primary means of mobility and seating. (No data could be obtained pertaining to populations of elders living in assisted living facilities (ALF) or Aging in Place.)

Out of the total number of manual wheelchair users in this country, the majority, (57.5 percent) of manual wheelchair users, are elderly (NCHS, 2004). According to 1994-95 data from the National Health Interview Survey on Disability (NHIS-D), the highest rates of wheelchair use are found among our geriatric population. 19 percent of those aged 65 or older, or about 900,000 people, use wheelchairs.

Not surprisingly, the majority of wheelchair users are women (58.8%). This is mainly due to the normally greater average lifespan of women and the reality that mobility devices are used primarily by the elderly (Kaye et al., 2000.)

Health, Age Related Disabilities, and Elder Use of Mobility Devices

Diminishing overall health is the main reason for loss of elderly mobility. There are 8 main conditions necessitating the use of assistive mobility technology for elders. Osteoarthritis creates disabilities affecting over 957,000 elder persons and is the dominant reason that mobility aids are prescribed. Cerebrovascular disease is a distant second, affecting 342,000 persons, as a main cause of disability. Age related cognitive impairments (senility) are the third most prevalent. They affect 233,000 persons. Next are orthopedic lower extremity impairments, affecting

226,000 elderly. Heart disease, hip problems, back problems, and rheumatoid arthritis are also common for elder mobility device users (Kaye et al, 2000). Other reasons for mobility device use cited by elders and caregivers are unsteadiness, stroke, frequent falling (Brooks et al., 1994), tiring too easily when walking, physical weakness that prohibited walking, and pain when attempting to walk (Pawlson et al., 1986).

As elders lose mobility with age, due to chronic disease, injury, or cognitive impairments, the ability to perform activities of daily living declines.

Gerontologists define functional status as an index of individuals' ability to perform self care tasks. Activities of daily living (ADLs) are basic self care tasks used by therapists to gauge a person's functional status. Bathing, dressing, using the bathroom, transferring, continence, and feeding are a few examples. (Horgas and Abowd, 2004.)

ADL's are broken down into a few categories based on an individual's level of function. For the purposes of this review, the most relevant category is Instrumental Activities of Daily Living (IADLs). IADLs are tasks that require higher levels of functioning such as food preparation, shopping, doing laundry, light housekeeping, using the telephone, managing money managing medications, and using transportation. (Horgas and Abowd, 2004.)

The number of US elderly age 65 and over with a chronic disability declined from 25 percent in 1984 to 20 percent in 1999. However, this gauge is deceptive because the elder population was in a state of growth that continues into the present. The number of elders with difficulty performing ADLs and IADLs increased from approximately 6.2 million in 1984 to 6.8 million in 1999. Problems with physical functioning become more frequent as we age. Thirteen percent of men age 65-74 reported they were unable to perform at least one of five activities, compared with 35 percent of men age 85 and over. Among women, 20 percent of those age 65-74 were unable to perform at least one activity, compared with 58 percent of those age 85 and over. The most frequently reported ADL difficulty was walking 2-3 blocks (NCHS, 2004). This serves as further reinforcement of the need for mobility aids like wheelchairs for this segment of the population.

Elders and Falls

Our kinesthetic senses lose sensitivity as we age. These senses are related to touch, pain, vibration, temperature, and motion. Little quantitative information is available, but these changes have been noted by researchers. The notable changes that occur in vibratory and motion sensitivity are the most important focal area for the purpose of this review. They give indications about various disorders of the nervous system

depending upon symptoms. Because of either a decrease in information exchange from receptors or a decrease in the use of vibratory information by the nervous system, elders lose perceptions concerning others moving them around or movement of their own bodies. There is reason to believe that one of these hypotheses is a contributor to the high incidence of falls associated with aging (Kroemer, 1997).

Wheelchair use and the Elderly

In 1986, Pawlson and his co-researchers did a survey of 50 wheelchair-using nursing home residents to determine the many uses of wheelchairs in this setting and the walking behaviors of nursing home residents. It was observed that there are significant numbers of residents in nursing homes that frequently use a wheelchair although they are capable of walking. Though, in most environments, there are major barriers to wheelchair use, nursing homes represent a stark contrast. In nursing homes, there are minimal barriers to wheelchair use, sometimes wheelchairs the norm, or at least a form of alternative transportation. When asked about the decision of why one would use a wheelchair instead of walking, fear of falling was the most common response. (That being stated, it makes sense that residents in this study also stated that they see their wheelchairs as a boon to their sense of wellbeing and security.)

There are social and environmental advantages come from being a wheelchair user in a nursing home. Being able to sit wherever they want, easily moving around in their rooms, and visiting other residents were some were some frequently noted social benefits of wheelchair use. Residents can gather at areas like nurse stations and hallways that sometimes have limited seating because they are in a wheelchair. (Pawlson et. al., 1986).

In 1994, Brooks and her co-researchers examined use of mobility devices in the geriatric population in nursing homes and assisted living facilities. They found that the most frequently used assistive devices were manual wheelchairs (87%), walkers (60%), and canes (54%). (Many residents used a wheelchair in combination with other walkers or canes). Over 50% of elders use their wheelchairs all the time while 14% used their wheelchairs to move for long distances. (Brooks et al., 1994).

That same study also revealed that over 94% of elders used non-prescribed devices. The study found that 71% of all devices used by the study population were prescribed. However, some elders were using hand-me-down equipment from deceased spouses or gifts from family and friends (8.3%), and/or self-purchased equipment (38%).

In their 1994 study, Mann and associates found that in 30% of the cases studied, elders received hand-me-down chairs or selected a chair based

on a recommendation from a friend, relative, or neighbor. It was found that only 40% of the participants involved health professionals in selecting their wheelchair. However, Wheelchair users that involved a health professional in their selection process had an 86% satisfaction rate with their equipment and a significantly smaller number of problems with their equipment.

Use of recycled or self-selected equipment is not recommended unless a trained physician or therapist can check to see if it properly fits the user, is safe for them to use, and if they need to be trained in its proper use (Brooks et al., 1994).

The “Typical” Elder Wheelchair

Medicare uses a series of designations for manual wheelchairs called “K Codes” for assigning wheelchairs to users based on their functional needs. The codes range from K0001 - a base level depot chair to K0009 – a custom manual wheelchair base. As a general rule, depot chairs are inexpensive. They should be used for transporting an individual from point a to point b and then transferring them into a more suitable seat.

Equipment dealers to nursing homes are dependent on Medicare, Medicaid, and nursing homes' equipment budgets for payment. Unfortunately, Medicare and Medicaid officials and nursing home administrators usually seem to look only at cost per unit. Manufacturers develop wheelchairs based on mass specifications. Most want to supply the largest number of a single conventional wheelchair design that they can sell at the lowest cost. Thus, equipment dealers stock only one or two chair designs that offer few fitting options or features (Redford 1993). There is typically very little if anything that can be adjusted to fit the user on this type of chair (Cooper, 1995).

The most commonly available type of wheelchair covered by Medicare for use by elders has a folding x-frame folding frame with a vinyl hammock seat and back (Redford 1993). This type of wheelchair is commonly referred to as a depot or institutional wheelchair (See Figure 1). The design was developed in the 1930's by Everest and Jennings, used heavily by injured veterans in the 1940's, and remains relatively unchanged up to the present. It provides mobility to users, but it is not an ergonomically sound design for long-term-use (Cooper, 1995) or user comfort and function (Rader, Jones, and Miller, 2000).

Depot wheelchairs don't suit the needs of people who use wheelchairs for personal mobility because: they are designed to be inexpensive, accommodate a wide range of body sizes, to be low maintenance, and to be attendant propelled. They are generally heavy (weighing anywhere from 32 to 56lbs.) and have poor performance characteristics. (Cooper, 1995).

A typical depot wheelchair has swing-away footrests, removable armrests, a frame that utilizes a single cross brace and solid tires. The armrests serve their intended role while seated, help to keep clothing out of the wheels, and aid with egress and stabilizing during transfers. Most depot chairs fold for storage or to fit the chair into a car. (Cooper 1995).

The frames of depot wheelchairs are usually made from bent and welded low carbon steel tubes, a common material for wheelchairs. Because it is an inexpensive steel that rusts easily, the tubes are usually chromed, powdercoated, or painted (Thacker, Sprigle, and Morris, 1993).

Depot chairs usually use solid tires and mag wheels for low or no maintenance, although this tire and wheel combination tends to compromise ride comfort. (Cooper 1995). The high rolling resistance and

lack of shock absorption afforded by this wheel type makes for inefficient propulsion and discomfort over uneven or rough surfaces.

Another type of chair prescribed to elders is the gerichair. Gerichairs are larger wheelchairs that resemble a naugahyde-covered recliner on wheels. They have small wheels, poorly padded seating with high backs and no seat adjustments and are attendant propelled. (Redford, 1993). They are very heavy, difficult to maneuver, far too large for the occupant, and lack any adjustments to properly suit the user needs of elders. Unfortunately they are often prescribed to 'problem cases' where individuals are absolutely unable to stay positioned in a depot wheelchair. (Rader, Jones, and Miller, 2000). One cannot change the load on the torso during long-term sitting – a huge reason for discomfort by those who use them. However, there is a new generation of these chairs that helps to eliminate some of these problems (Redford, 1993).

Some manufacturers have created postural seating solutions for older adults. This type of dependency chair offers modular adjustable seating systems to custom-fit patients and features such as self-propulsion capabilities via large, quick release front wheels. (Redford, 1993).

Wheelchair Problems and Elder Users

A 1983 study performed in Great Britain found that of the 200,000 wheelchair users in England, over 2/3 were older adults. They also found that many of these chairs had inefficient brakes and flat tires (Haworth, Powell, and Mulley, 1983).

Before one can define elder wheelchair problems, one needs to determine how they received their chair in the first place. Though information exists on how elders in nursing homes and assisted living acquire their wheelchairs, little info exists on how non-institutionalized older persons received their wheelchairs. In (1996), Mann, Hurren, Charvat, and Tomita studied wheelchair problems with a more specific bent toward frail elder wheelchair users that are aging-in-place.

University of Buffalo 's RERC on Aging found that 40 percent of elder wheelchair users reported at least one problem with their wheelchair during their Consumer Assessment Study (CAS) (Mann, Hurren, and Tomita, 1995). Mann and associates randomly selected 19 of the participants from the CAS study with wheelchair problems to be involved with their 1995 study. From the 19 participants, they found 27 total wheelchair problems. Maintenance problems included flat tires, broken wheels and leg rests falling off. There were user fit problems like missing armrests and

general discomfort while in the chair. 25% of the participants could not propel themselves independently, but wanted this freedom . Many of the participants had general difficulties with their chairs because of weight (during propulsion and while attempting to lift the chair) and size (could not get through some doorways in their home).

Pawlson and his co-researchers also found that there was little or no formal prescription for a new wheelchair if an elder or their family requested one. Usually a family requested a wheelchair to procurement and then one was provided by social services. Formal wheelchair prescription and training is extremely important in its use. A properly fitted wheelchair can greatly extend their mobility. However, an ill-fitted wheelchair can be disastrous for an elder's health and wellbeing.

One of the greatest problems with elder wheelchair use is lack of proper equipment training. Therapists and healthcare professionals need to be more actively involved in wheelchair training and safe use of wheelchairs. In their elder wheelchair problems study, Mann and his co-researchers found that only less than 20% of their participants received training on the use and maintenance of their wheelchairs (Mann et al., 1996). Elders need reinforcement on how to safely transfer, shift their weight, and

maneuver their wheelchair effectively to maximize their mobility and quality of life.

It was also found that many elders used their wheelchairs as a rolling walker. One cannot stop a wheelchair easily when it is used in way. There is no access to the brakes while pushing a wheelchair. Elders who use a chair in this way are at risk for falls. They note that therapists or other healthcare professionals who see or encourage this practice should realize that this is a dangerous practice (Brooks et al., 1994).

Seating

The Importance of Proper Seating for the Elderly

Because so many elders spend the majority of their time sitting, seating is of particular concern. Seniors in nursing homes are of particular concern because they are usually limited to a seated existence. In 1993, John Redford published the authoritative review article on elder wheelchair and static seating in long term care institutions for the time. It is still cited by many authors with interest in elder wheelchair mobility to this day. He states that too many old people who are sitting too many hours a day in wheelchairs that provide too little postural support or mechanisms for

pressure relief over vulnerable skin surfaces. He notes that the disabled elderly need seating that “provides comfortable, functional posture and that protects the skin and musculoskeletal system against injury or deformity.” Attention has been shown to developing seating solutions for the disabled young. Though study results already support that a need exists, little attention has been paid to developing seating for the disabled elderly.

In 2000, Rader, Jones, and Miller created a review article covering many of the issues mentioned by Redford, but from a more ADL-based approach. They show that all too often many elders are forced to sit in wheelchairs that are too large for them and lack proper seating solutions. Their paper illustrates how proper seating improves mobility and quality of life.

There are several wheelchair seating studies that illustrate elder user needs. One performed in Dundee, Scotland by Bardsley (1984) showed that problems in wheelchair seating were related to: elders using chairs that are inappropriate for their body size, unaddressed postural instability issues, difficulty rising out of the chair from a seated position, and the ability to move the chair while seated. A study in 1992 by Shaw and Taylor showed that 80% of the residents had at least one seating problem. These

problems create discomfort, reduce mobility, generate poor posture, and create safety risks for elder wheelchair users.

In 1990, Epstein noted in his study of a New York nursing home that poor seated posture results mainly from the patient being able to slide or lean to one side of the chair. This indicates that their chair is too wide. The long term results of this slumped seated posture are discomfort, pressure on the disks, and stretching of the ligaments and muscles – eventually creating a kyphotic lumbar posture.

Hammocking sling seats provide an unstable base for sitting. This seating type encourages forward slipping. This slipping results in pelvic tilt, causing the hips to abduct and internally rotate. This results in kyphotic and other asymmetrical spinal postures. (Bar, 1995). The seats are usually made from vinyl or naugahyde. Cooper states that these 2 materials deform substantially when loaded and are inappropriate for use as seating materials. As the sling seat upholstery stretches and deforms, there is also an increased risk of skin injury or pressure sores at or near the trochanters. (Bar, 1995)

Pressure sores are of huge concern elders. Though specialized cushions exist that meet the needs of patients at risk for developing decubitus

ulcers, that distribute pressure more evenly, dissipate heat, or reduce friction on the seating surface, they are seldom used due to cost concerns. Medicare tends to look more at expenses and less toward function and comfort. The irony is that the purchase of a pressure relief cushion or better-fitting wheelchair is far less costly than the price of decubitus ulcer care (Redford, 1993).

Aging is associated with increased difficulty getting in and out of chairs, but this is a fact rarely considered by chair designers (Finlay et al., 1983). In 1991, Hanger, Ball, and Mulley studied elder static seating at an outpatient clinic. They found that 50% of their 97 subjects had difficulty in rising from the clinic chairs due to incorrect seat heights and a lack of armrests. In another study at an English nursing home, 48% of the residents could not get up from their chairs without assistance. When the same group was given a chair with armrests, 87% of the residents were able to arise from the chair with ease (Fernie and Letts, 1991). Though static seating was studied, similar problems exist with wheelchairs. Elders need to be able to have affordances for ease of ingress and egress, so their wheelchair should accommodate for this.

Standard wheelchair designs do not allow effective use of cushions. Most cushions are 2" thick or over. This causes users to sit in a position that is too

high for most tables. Sit to stand maneuvers may be difficult because the feet cannot touch the floor (with arm propellers that use footrests) (Bar, 1995.)

Many non-ambulatory elders perform lateral transfers to move from their chair to another object, This is accomplished by parking alongside an object like a bed or chair and sliding sideways. Removable armrests enable elders to more easily perform this maneuver. (Ferne 1997) Based on analysis of the current state of the art in flip-up and removable armrests, there is significant need for improvement. Armrest removal and flip-up mechanisms are heavy and unfriendly to elders or caregivers who must deal with them during ADLs and client interactions.

Good Elder Seating Solutions

Wheelchair Fitment and Comfort

Good seating solutions provide a foundation for a greatly improved quality of life for geriatric wheelchair users. Comfortably-fitted elders are able to sit in their chairs for longer periods of time. They are less prone toward agitation and restlessness and have significantly reduced chances of skin breakdown. Good fitment allows for improved self-propulsion.

Effective positioning also gives users greater autonomy over their lives.

Older adults can maintain a healthy self-image by being able to perform grooming and hygiene tasks. Good trunk posture allows the chest cavity to expand more than a slumped position and provides elongation of the abdominal region, allowing for better function of the organs therein.

Consequentially, elders can speak better, have improved respiration, eat and digest food more easily, have higher levels of activity, and reduce their risk for aspiration. Good pelvis and trunk position also allows users to easily make eye contact with others and to be more aware of their surroundings. This generally improves communication and socialization. (Rader et al., 2000).

Good seating also reduces caregiver burden. Proper seating allows elders to independently transfer or reduce the amount of caregiver assistance needed for transfers. It also increases the likelihood of being able to feed and toilet oneself independently. This stands to greatly reduce the shoulder and back injuries that plague elder care staff. Comfortable seating also reduces instances of behavioral symptoms (crying, yelling, etc.). due to decreased levels of client agitation. (Rader et al., 2000).

It is also extremely important that the user/patient helps to select the wheelchair that they will be using. The prescriber must consider factors

like the user's environment (indoor and/or outdoor use?), does the user need to transport their wheelchair? (How light a chair can we acquire for the patient using available funding?) Does one wheelchair fit the client better than another? What is the patient's propulsion type? Does the user need to purchase a wheelchair lift for their car?) Prescribers must also take durability and maintenance issues into account to responsibly meet the needs of an older user. (Redford, 1993).

Elder Seating Ergonomics

For a person to sit comfortably there must be a balance of and moments and forces in all planes. Good seating posture means that the head and neck are vertical, the hips are flexed at 100 degrees, the knees are flexed at 90 degrees, and pressure exerted by the head, arm, and torso is over the ischial tuberosities (Letts, 1991). However, a seat angle in this range may hinder egress from the chair for some individuals (Bar, 1995). For particularly kyphotic clients, a 15 degree recline may also be in order. This allows for better positioning of the body in space and allows ease of eye contact. (Rader et al., 2000). Several wheelchairs are on the market that meet the recline needs of elders with a fixed kyphosis yet still allow for independent propulsion.

The standard seat height of a conventional x-frame wheelchair is 490mm (20"). However, based on a 1987 study, the recommended seat height for a wheelchair is between 470mm and 490mm (18.5" to 19.5") with a 9° seat rake (seat angle). Seat depth should be 50mm to 75mm (2 to 3in) between the popliteal space and the front edge of the seat (Fernie, Holden, and Lunau, 1987).

As mentioned above, standard seat height is 490mm (20"). The seat width is normally 18 inches wide. These dimensions are ideally suited to adults that are 6 feet tall (Rader et al., 2000). This makes it hard to fit shorter patients. In this case, a low-seat chair, typically prescribed for hemiplegic patients (patients that use a combination of one arm and one leg to propel), would be the best solution. (Redford, 1993). Therapists refer to these lower height chairs as "hemi-height." These chairs ease foot propulsion (better foot contact with the ground) and reduce pressure across the popliteal space. This is an especially important factor to consider, especially considering that the majority of elder wheelchair users are women and usually of shorter stature than most men. Smaller wheelchair sizes that take more than just seat height need to be developed that better fit more petite elder wheelchair users.

Because comfort is not independent of ergonomics, mobility is dependent upon seating (McLaurin 1990). Seating provides a base for propulsion, therefore proper positioning is key to biomechanical efficiency. In 1987, Fernie, Holden and Lunau stated that a wheelchair should have a seat angle of 9 degrees for optimum comfort. This finding on seat angle was supported further through a study by Aissaoui and associates in 2002, but with a focus on optimum biomechanics for older wheelchair users. They tested elder users through 9 different combinations of backrest and seat angle. They discovered that a seat angle of 10 degrees provided optimum power output for elder users. This data overlaps the findings for seating comfort as well as a 10 degree seat angle requires the hips to be flexed at 100 degrees.

Wheelchair Cushions

Prescription of the appropriate cushion to serve the specific needs of their user is key to the comfort and health of elders. Seat cushions are contoured or flat to provide relief over critical areas like the ischial tuberosities (Sprigle, Chung, & Brubaker ,1990). Cushions need to be firm to permit movement for pressure relief. Cushions that are too soft compromise position and posture. Elders need flat cushions with

waterproof, easily cleaned covers to ensure correct positioning, proper posture and pressure relief.

As mentioned earlier, cushions should be supported by a firm base. Many solutions exist that add little weight to the chair while providing predictable support for the seat cushion. (McLaurin, 1990). A rigid seat insert should be used or seats should be constructed of textiles with high tensile strengths like nylon, Kevlar, and cotton canvas (Cooper 1995). Fernie states that sling seating provides inadequate postural support and stress distribution for elders and instead recommends only solid seat to act as the foundation for an elder seating solution. A 1990 study by Harms and a 1990 study by Shields and Cook also support using a firm base in lieu of a sling seat. Harms study found that wheelchairs with solid-based seats with firm padding and firm seatbacks with contoured back and neck cushions increased user comfort and improved posture. Shields and Cook support the setup suggested by Harms, but recommend a back recline angle 100° from horizontal to reduce pressure on the spine and skin about the lumbar area.

Cushion Types

There are several options for seat cushions that can be prescribed based on elder needs. Though egg-crate cushions are readily available and

cheap, they do very little in terms of pressure relief and last no longer than 6 months (Noble and associates, 1986). A flat viscid elastic foam cushion is best for patients who may occasionally forget to shift position - users at moderate risk for pressure sores. They have some contour and distribute pressure evenly. There are also layered versions of these cushions that have a soft layer of foam on top, a middle layer of denser foam responsible for pressure and shear reduction and temperature management, and a bottom layer that prevents the cushion from bottoming out. (Redford, 1993)

Foam cushions have poor breathability and heat exchange. Individuals living in warmer climates are at increased risk for pressure sores due to the possibility of exposing sensitive tissue to sweat and moisture. With incontinent patients, if a waterproof cover is not used, the foam could be permanently damaged - destroying weight distributing abilities and causing odor (Rosen 2005).

Bladder cushions filled with air or silicone gel support cushions are best for patients at high risk for decubitus ulcers. Air bladder (or air cell) cushions have the advantage of inflating one side more than the other to accommodate for any anthropometric imbalances (Redford 1993). Their disadvantages include setup time – therapists must be careful,

overinflation is just as dangerous as underinflation (Rosen 2005); rejection – some patients are not comfortable sitting on them due to a feeling of instability; and air loss – creates loss of skin protection and creates a maintenance issue for caregivers (Redford, 1993).

Silicone gel bladder support systems are constructed in combination with foam to provide both pressure relief via gel and support with foam. They provide good pressure distribution and they are adjustable to correct for anthropometry via the addition or removal of pads below the cushion surface (Redford, 1993). Gel cushions also provide a cooler seating surface than foam to reduce problems related to moisture. Unfortunately, over time the gel can shift away from areas of high pressure, thus the user can bottom out. It is easy to correct by shifting the gel back into position, but it is still a maintenance issue (Rosen, 2005.)

Another cushion option lies in honeycomb cushions. It uses multiple layers of silicone honeycomb of differing densities to support the bony prominences and surrounding anatomy correctly. The honeycomb surface is firm to allow lateral transfers, the cushion has tiny perforations in the honeycomb for good ventilation, and the cushion itself is antifungal, antibacterial, odor resistant, machine washable & dryable for incontinent

users. It requires the least maintenance of all the pressure relieving cushions. (Rosen, 2005).

A series of wicking covers are also available for wheelchair cushions. (Rader et al. 2000). When used with the cushion systems above, they form a combination defense in the prevention of pressure sores.

Seatbacks

Firm seatbacks should also be used in combination with proper cushioning. It is important not to exaggerate lumbar support with elders. Older persons' spines are stiffer in extension and the spine does not have the ability to achieve the anterior flexion to fit a backrest of this type. Consequently, it can create a more slouched posture or make the user slide forward in the seat (Ferne, 1997). The more disabled the patient, and the greater the amount of postural control desired, the higher the seat back needs to be. There are special seatback components to address the specific needs of patients with lumbar lordosis, kyphosis, or scoliosis. Due to the specificity of these needs, a seating specialist should be consulted to create a setup that is custom tailored to the patient (Redford, 1993).

Ingress and Egress

For ambulatory elders, being able to rise from a chair is of great importance. The main factors affecting egress are seat height, armrest design, cushioning depth, and seat rake (Holden, Fernie, and Lunau, 1988).

Influences from static elder seating may prove to be good food for thought on wheelchair seating for the elderly. The ability to rest one's feet flat on the floor with the knee flexed at a 90° angle does not optimize the process of standing up. This type of chair traditionally has a higher seat with flip-up the footrests. The footrests support the feet while sitting. Ease of egress on an elder chair with footrests occurs because the knee has less flexion than a chair without footrests. A word of caution, drawbacks exists when geriatric users with a cognitive or visual impairment sit in this chair type. These users could accidentally stand on them if they forget that the footrests are in place or trip over them if they are deployed while attempting to enter or exit the chair (Fernie 1997). The same problem exists when footrests are used in elder wheelchair seating.

Obviously footrests are another area of potential improvement in seating for the elder wheelchair users. Currently, if an unstable frail elder user tries to stand up while the footrests are in place, they could become seriously

injured. Also, when footrests are removed, they are usually never found again. However, some food for thought exists from a 1990 study and design document by Frank and Abel. They created a lowering footrest for attendant and transit chairs with innovative safety features that have definite applications for frail elders.

Wheelchair Procurement for Elders

In order to determine the seating needs of an older adult, an occupational therapist (OT) or a physical therapist (PT) needs to do a seating assessment. This seating assessment forms the basis for prescribing a wheelchair and cushion/seating system that best meets the needs of the user. This seating assessment must be prescribed by a physician. Via a mat evaluation, determination of the individual's function and an interview or observation of the client's living environment(s), the therapist determines the elder's equipment needs and requests funding. (Rader et al, 2000).

Rader and her co-authors note that it is important to be connected with a reputable and knowledgeable durable medical equipment (DME) supplier. Redford notes that DME tend to deal more with K001 chairs due

to the fact that Medicare and Medicaid push them in that direction. It seems that Rader, Jones, and Miller have had more favorable experiences with their DME providers or that they have a greater success rates in acquiring truly individualized seating solutions. They note that their DME sources have often offered demonstration/trial periods (of one 2 two weeks) to test out wheelchairs in order to assure that they have prescribed the best solution(s) for their clients. They trust the knowledge of their providers and state that they are an essential resource in finding the best solutions to elder needs because they are most aware of what is going on in the wheelchair industry and can even offer advice on how to handle the claims processing to Medicare.

Once the therapist is sure that she has selected the best solution to the problem, the physician must now write another prescription for the equipment. Usually, this paperwork is filled out by the therapist and then the request forms are signed by both the physician and therapist. (Rader et. al., 2000).

It is often difficult to obtain the necessary funds to acquire individualized seating equipment for elders. Even when a therapist can prove evidence of need or improved quality of life. Rader and associates show that there are 3 main funding sources for durable medical equipment for elders:

Third party payers, the client or family's personal funds, and charitable organizations.

Third party payers like Medicare and Medicaid use case managers that review DME prescriptions on a case by case basis. This process takes anywhere from 6 weeks to 3 months. Part of successful acceptance of payment by a 3rd party payer involves the therapist becoming an advocate for the client. The more the therapist can get the family and physician on board, the higher the likelihood that a claim will be accepted. It should be noted, however, that it is difficult to get Medicare to pay for an individualized wheelchair for an elder in a nursing home. It is easier to receive the exact device prescribed by one's therapist if they are aging in place or living independently. The reason for this is based largely in out-of-date federal policies and the process is quite discriminatory. Using personal funds to purchase a wheelchair or getting aid from charitable organizations can be eased by using the wheelchair trial period to convince the client and/or their family about the advantages of an individualized wheelchair seating solution. Again the therapist needs to have their client's best interests in mind and be an advocate. (Rader et al., 2000).

Designing Better Wheelchairs for Elders

Changes as we Age

Height is an essential element used in developing assistive devices. A reality of aging is that we lose height as we get older (beginning in our 30's). Combinations of the following factors play a role: flattening of tissues - spinal discs, vertebral bodies, weight-bearing cartilage; kyphosis; scoliosis; feet becoming flatter; and possible bowing of the legs (Kroemer, 1997).

Bones gain diameter, becoming more hollow and porous as we age. These are some of the indicators of osteoporosis. Changes in bone structure are connected to breakage during falls or other accidents. People who are less active are more prone to these types of bone-related injuries as they age (Kroemer, 1997).

There is often a loss of flexibility as joints lose elasticity, thickness, and lubrication. This leads to loss of range of motion and arthritis in joints and the spine. (Kroemer, 1997).

Active individuals can sustain much of their muscular capability as they age. However, in less active individuals, disuse leads to atrophy, decreased circulation, and eventual loss of strength (Kroemer, 1997).

Respiratory function decreases with age. The lungs are less able to exchange gases efficiently. Due to loss of strength, the intercostal muscles are less able to create "breathing space," thus reducing lung capacity.

Blood supply often decreases due to changes in blood vessel elasticity and increased deposits along their walls. This is often worsened by a decrease in blood-cell production in the bone marrow. This leads to inefficient processing of energy and waste products in the blood.

The heart changes as well as we age. Heart output reduces. In some cases, the heart may become smaller. Other changes resulting from this are increased recovery time after activity.

Sensation and perception are reduced as we age. Sensation (receiving stimuli) becomes reduced due to fewer sensor cells in the skin while perception (interpreting stimuli) is slowed. This, coupled with decreased bloodflow slows information processing, reaction time, and responses to external stimuli (Kroemer, 1997).

As we age changes in the brain begin around age 50-60. These changes are more observable by age 80. These correlates well to the prevalence of dementia cases found in elders 80 and above (Kroemer, 1997).

Changes in vision are connected to factors mentioned above and the fact that the eye, much like a camera, loses precision as it ages.

(Kroemer, 1997) There are also age related-diseases like macular degeneration, cataracts, and diabetes that can affect elder vision as well. Decreases in vision are important to take into account when designing assistive mobility devices for the elderly. As eyesight worsens, elders lose some awareness of their environment. This can affect if an elder can effectively and safely move in their environment.

Use of Anthropometry in Designing Elder Products

Currently, body dimensions for select age brackets are generated by measuring people within certain age groups and then averaging their measurements (a.k.a, a cross-sectional approach). Because the young adult population does not change very much from 20-50 (other than a slight reduction in stature), this approach works well for creating an accurate overall description of the young adult population. However,

using a cross-sectional approach is problematic when used to develop a description of elders as they age. Some older adults change dimensions rapidly as they age while others do not. This creates too much variance in the sample. This variance is compounded by the fact that age groups are normally bracketed by decades instead of years. Chronological age is not the best for studying the anthropometry of the elderly. Instead, changes need to be observed over time, not just in a brief, one-time measurement session. Longitudinal studies would be ideal because selected groups of individuals can be observed over many years. This would help to form a more accurate picture of how changes occur in anthropometry. (Kroemer, 1997). The current stores of elder anthropometry could be quite flawed. It is fortunate that there are a range of wheelchair widths, seat depths, and heights available to suit elder needs on a more individual basis. However, if an accurate set of elder anthropometrics could be created, designers striving for universally designed products and creators of assistive technology could begin to see trends in older populations. This could be a boon for creating products that one can get 'off the shelf' to enable elders. By decentralizing the channels in which elders receive these products, and bringing them to mass markets, more elders can reap the benefits of these devices (Fernie, 1997).

Frame Design

Thacker, Sprigle, and Morris state that (as a general rule) for propulsion on level surfaces wheelchair weight is usually a non-issue. If a user switched from a 45 lb standard wheelchair to a 25 lb lightweight wheelchair, their rolling resistance would only change by 7.5%. According to Thacker and his associates, unless a wheelchair user lives in an extremely hilly environment, folds and deploys their wheelchair multiple times over the course of a day, or is extremely active, there is little reason to obsess about wheelchair weight. They note that, "When one considers the proportionality of weights of the wheelchair and user, it should be obvious where the greatest weight reduction potential lies." The aforementioned observations hold true in the case of active younger wheelchair users.

However, when one considers the realities of active frail elder wheelchair users Thacker and his co-authors' viewpoints no longer hold true. Many elder wheelchair users fall below that weight range noted in their rolling resistance example. Most elders in institutional settings use wheelchairs that are 45 lbs or over. Unfortunately, frail elders usually lose endurance and energy as they age. A lighter weight wheelchair can enable older adults to conserve energy and have greater levels of activity than with a heavier chair. (Rader et al. 2000). With a heavy wheelchair, elders are constantly fighting the inertia of their stopped wheelchair. The heavier a

wheelchair is, the harder it is to break its inertia from a stop and while in motion to make a turn. Many elder users in institutional settings have an inefficient propulsion stroke or use foot and/or combination propulsion. Some of this is due to poor access to the wheels. If a wheelchair is the correct width for the user, elders can reach the wheels better and use their limited energy more efficiently. These facts are of concern to maintaining older adults' quality of life. Wheelchair weight needs to be taken into account for elder wheelchair users. Reduction in rolling resistance via a lighter wheelchair could improve their quality of life and keep elders more active for a longer period of time.

Ultralight wheelchairs were originally developed in the 1970's to meet the needs of disabled athletes. They utilize a rigid, lightweight, frame for energy efficient power transmission. They also allow fitment like width and axle position. (Rader et al 2000.) These chairs usually weigh about from 11kg to 17kg (24 to 38 lbs). Conventional chairs weigh at least 18kg (40lbs). Though most ultralight chairs are very minimalist in their design, they offer firm seats and seatbacks and are highly durable. Because these chairs are not designed to hinge about the roll axis, they do not fold like an x-frame chair. Instead they use quick release wheels and often have seats that fold down to make the chair more compact. Despite one-step foldability, a study by the American Association of

Retired Persons (AARP) showed that ultralights' durability and energy-saving designs are appealing options to elders (Redford 1993).

In a 1990 article for the Journal of Rehabilitation Research and Development, Colin McLaurin, wrote about an affordable, lightweight wheelchair that he co-developed at the University of Virginia. It is extremely lightweight and allows the user to move the seat forward or backward through a range of 5" while seated. The ability to move the seat is ideal for elders to ease the ability to transfer while still allowing users to be in an appropriate position for propulsion. Through a combination of quick release wheels and simple hinge mechanisms, the chair folds into an extremely compact and portable package. This creates a huge advantage for highly active elders or those that have limited space in their living areas.

The dominant wheelchair type prescribed to elders in the UK is referred to as a type "8L or 9L." This is equivalent to a K001 here in the U.S. There are about 144 variations of this chair available in the UK. They are just as non-adjustable and bad for long-term seating as a K001 chair, as well.

However, in recent years, a modular version of this wheelchair was released to the market . The chair uses a basic frame in combination with

a small number of sub-assemblies. This allows for over 25, 000 custom configurations to meet user propulsion and seating needs (Bar, 1995).

Propulsion and Maneuverability

Research has determined that 58% of nonambulatory elders in nursing homes experienced a serious problem concerning limited mobility due to the use of a standard wheelchair (Shaw and Taylor, 1991. & Perks et al., 1994). In 1995, Simmons and associates held a 2 day observational study at a nursing home. They found that 71% of the residents were capable of various levels of self propulsion. However, the participants were found to only propel their chairs only 4% of the time during their waking hours. These studies have shown that elders have difficulty propelling a K1 chair to weakness and pain. This results in impaired mobility.

As a group, the elderly are known to experience significant age-related shoulder and upper extremity weakness (Ferguson-Pell, 2005). The arm and leg strength of the average older person is reduced by about 50% compared to when they were 20 years old (Dreyfuss and Associates, 2002). Flexibility of the shoulder also comes into play. A 1999 study of 61 independent elder women were studied to see how age flexibility. It was

found that elders had 9% less internal shoulder rotation and 16% percent less external shoulder rotation than the typical range of motion noted in the American Academy of Orthopaedic Surgeon Standards (Kalscheur et al.,). A combination of studies indicate that between 33% and 57% of wheelchair users report pain in the shoulder joint and 49% to 73% mention pain in the wrist joint (Boninger et al., 1999). This gives indication that it could potentially be uncomfortable to reach back to rotate a wheel in the current axle location found on most chairs (behind the COG).

In 2000, Boninger et al. created a study to see if there was any correlation between axle location, push angle, and frequency of stroke. The published study results show that moving the axle forward (horizontally) in relation to the shoulder joint reduces stroke frequency and handrim force (See Figure 2). The investigators concluded that moving the drive wheel axle forward improves user biomechanics. Though this study utilized participants with spinal cord injuries, but has indications for the elders. For the greatest mobility, the axis of the wheels should position the wheel axis directly under the COG of the combined wheelchair and user (McLaurin and Brubaker, 1991). If the drive wheels were moved closer to the COG, closer to a neutral shoulder posture, and within the average elder ROM for the shoulder, it could make for a potentially more comfortable, efficient, and maneuverable configuration for elder mobility.

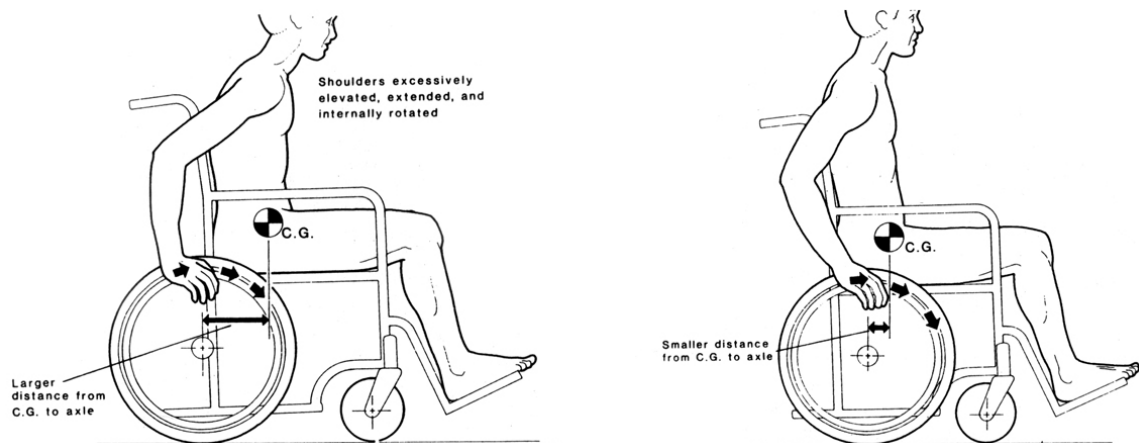


Fig. 2: The location of the COG for a hypothetical wheelchair with a rider (from US Department of Veterans Affairs. Choosing a Wheelchair System, Journal of Rehabilitation Research and Development-Clinical Supplement No 2. Baltimore, MD.)

As stated previously changing the location and configuration of the drive wheels is another opportunity for improvement in designing a wheelchair for elders. However, without special design considerations, a wheelchair of this design has an increased chance of tipping backward. Often times, the setting of the wheel axle becomes a compromise between performance and stability (Fernie, 1997). However, some designs exist that avoid this compromise. Several efforts have been documented at attempts to create chairs in which the wheel axle location is directly beneath the users' center of gravity instead of just near it.

After researching past design attempts, two noteworthy attempts at this type of design come to the fore. In 1976, Permobil created a manual wheelchair that had 2 main drive wheels with casters fore and aft of the

COG to balance the chair (See Figure 3). They touted the benefits of having the wheel location over the COG and its benefits in terms of maneuverability.

U.S. Patent April 27, 1976

3,953,054

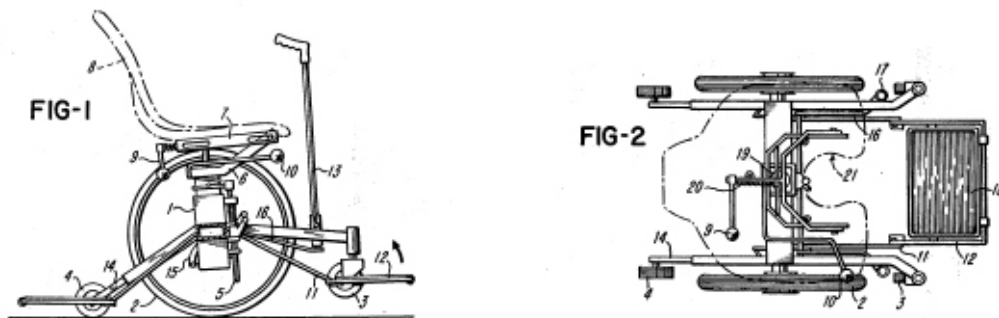


Fig 3. Permobility's 'Hand Operated Wheel-Chair' patent (1976)

Colin McLaurin, as a professor at the University of Virginia developed a design for a "Center of Gravity Wheelchair with Articulated Chassis" in 1982 (See Figure 4). The chair was configured in a "Diamond Configuration" with the main drive wheel located underneath the COG and a caster mounted fore and another caster aft of the main drive wheels mounted to an articulating arm. The intention of this chair was to create an extremely stable caster setup for crossing slopes sideways and an articulating rear caster that allows users to safely lean back when traversing obstacles like curbs. Though neither of these efforts are focused

on elder range of motion, these are potential idea-generators for future work in elder wheeled mobility.

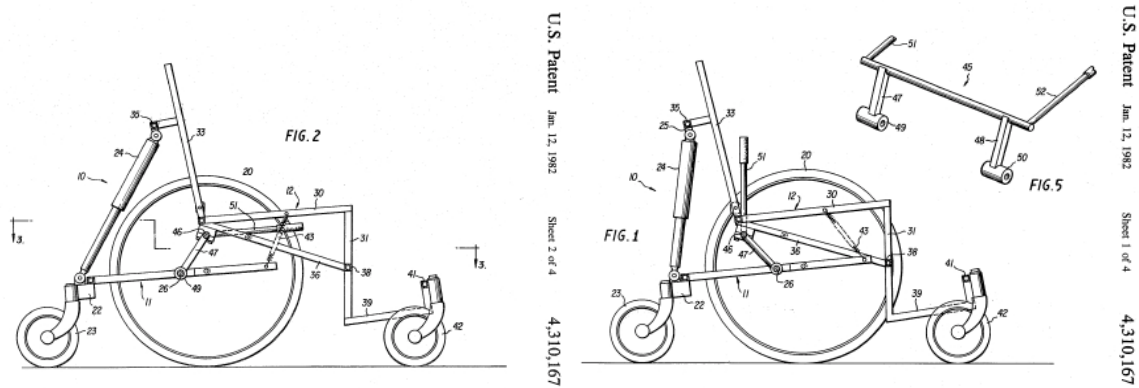


Fig 4. Colin McLaurin's "Center of Gravity Wheelchair with Articulated Chassis"

Pushrim activated power-assist wheelchairs (PAPAW) are another type of advancement in manual wheelchair technology that could positively affect elder propulsion. With this system, users push the handrim to activate lightweight motors that help to drive the wheels for a few seconds. Users must continue to push the handrim as if they were propelling a standard wheelchair to keep a PAPAW moving. Though PAPAW systems batteries and wheels increase the overall weight of the wheelchair, their efficiencies are a boon for those with decreased endurance. A 2004 study by Levy et al found that use of a PAPAW by elders resulted in reduced heart rate elevation, perceived exertion, and

EMG activity. Currently, this mobility innovation is quite new, thus this type of elder mobility solution is quite cost prohibitive. However, it could become a cost effective means of extending elder mobility as the technology matures (see Fig 5).



Fig 5. E-Motion Power Assist Drive Wheels

Materials

Plastics have potential advantages in frame and component design. Reinforced plastics and composites with honeycomb cores are light and strong. There are available cost estimates that show components like a side frame could be created in a one step process, eliminating further finishing processes. Parts like this could be made for as little as \$15/part when manufactured in quantity (McLaurin 1990).

Tires

Finding a tire type that maximizes comfort and efficiency while minimizing tire maintenance is essential for maintaining the optimum mobility of elders, regardless of whether they live independently or within an institutional care setting.

Pneumatic tires are generally believed to be high maintenance - they require attention to air pressure and can be punctured. (Thacker et al. 1993). Currently, they are seldom used in nursing home environments.

Hard rubber tires are low maintenance, but rolling resistance studies have shown that it may require over 30% more effort to propel hard rubber tires than pneumatic tires of the same size (Gordon et al., 1989). Some non-pneumatic synthetic tires have good results in terms of rolling resistance, but lack the comfort of a pneumatic tire. (Klauzarich et al 1985). A 2004 study by Sawatzky et al. found that many pneumatic tires at 25% of their recommended pressure still had lower rolling resistance and lower user exertion than solid tires. They also found that the overall cost of using pneumatic tires in an extended care setting is far less than originally thought. They note that the original purchase costs of a solid tire versus pneumatic tire are comparable. They also note that although tire pressure needs to be maintained for pneumatics, these tires only need to

be pumped once a month to maintain adequate pressure. Their study found that tire inflation takes less than 2 minutes (or one hour/year) for three wheelchairs and that risk of puncture is quite low in a typical Extended Care Unit (about 1 puncture every 3-5 years).

Many indirect costs may exist from using solid wheelchair tires. Wheelchair users may experience greater fatigue from the higher rolling resistance of a solid tire. This creates a state where staff ends up pushing residents instead of promoting independent wheeling. Fatigued residents that cannot wheel their chairs often end up staying in bed, increasing the chance of pressure sores, and allowing for muscle atrophy. (Sawatzky et al 2004.)

Additional benefits of pneumatic tires include: 1.) providing a higher traction surface than a solid tire or a handrim if the user has a weak grip. 2.) They also damp vibration transmitted to the occupant during independent and attendant propelled wheeling. (Gordon et al, 1989) 3.) Pneumatics benefit care staff as well by reducing strain on attendants as they propel residents.

Despite the benefits of using pneumatic tires, the likelihood of widespread acceptance within nursing homes and assisted living facilities is still limited.

Nursing, therapy, and maintenance staff are too often overloaded with work and not enough facilities have a dedicated staff that tends to the upkeep of wheelchairs. However, a solution may exist in a newly developed and field tested technology from Michelin called Tweel™.

Tweel™ is a non-pneumatic tire/wheel assembly that consists of a composite reinforced tread band that is connected to a flexible (deformable) wheel via rectangular, polyurethane spokes (see Figure 6).



Fig 6. Michelin Tweel

This tire/wheel structure provides weight-carrying ability, shock absorption, low rolling resistance, and improved handling with a mass similar to

pneumatic tires (Michelin NA 2005). This technology has already been showcased on Dean Kamen's iBOT wheelchair, Segway, and the lightweight Segway Centaur (SAE 2005). Michelin is pursuing low-speed vehicles at this time to showcase Tweel technology. Michelin has created Tweel casters with many of the performance benefits of a pneumatic caster without the weight and maintenance penalties. Tweel wheelchair caster technology is currently in development with good performance results. If a Tweel model existed for wheelchair drive wheels it could be a boon for both users who do use and do not use pneumatic tires. Reducing or eliminating regular tire and wheel maintenance (e.g. rim trueing) for pneumatic tire fans while creating a lighter weight solution to solid or semi-solid polyurethane tires with heavy mag wheels for the rest of the wheelchair market would create a blanket solution for drivewheel prescription. Advancement of Tweel technology would be a boon for wheelchair users of any age or ability.

Assistive Technology and Elder User Needs

According to Fernie and other leaders in the field, assistive device design is still in its infancy. Opportunities for device and technology improvement

surround the assistive technology markets. One doesn't need to look very far to find issues concerning usability, aesthetics, connotations, stigmas, and abandonment are key issues in rehabilitation engineering. These are some of the broader issues, but customizability and the ability to prescribe technology based on an informed analysis and interpretation of an individual user's actual needs are key strategies to creating designs that are truly successful for users of assistive technologies.

Developing a New Design Model for AT

When designing a wheelchair for a specific population like the elderly, one must ask questions involving user preferences. By looking at the bigger picture of all factors affecting the elder user's life, the designer can take the emotional picture of the user's needs into account as well. Some of these emotional concerns and how to approach them have been investigated by several researchers who deal with the prescription of AT devices.

Assistive technology's benefits far outweigh its flaws. However, when it comes to creating devices that are highly functional yet acceptable to the elders that use them, there is plenty of work to be done. A huge focus of AT research involves acceptance or rejection of assistive technology.

There is opportunity to involve universal design principles in the AT product development to improve user acceptance and community perceptions concerning AT devices.

Universal Design (UD) is the concept of creating products that are useable by people of all ages and abilities. Finding ways to create attractive devices that we can use every day and continue to use as our abilities decline with age is one of the key tenets of universal design. This is why UD is sometimes referred to as transgenerational design. (Ferne 1997). In recent years, UD principles have been a driver in creating products that are more elder friendly.

Ferne states that UD principles have applications for assistive technology design, but he states that this can only occur via a *limited version* of those principles. Ferne's design model is loosely based on UD principles to offer use to a wide range of users. It is possible to reap some of the benefits of UD principles while remaining true to the functional needs of those with significant functional limitation. However, one needs to target distinct populations of users with a wider range of disabilities instead of creating devices that work for everyone. Both function and aesthetics can combine to create AT for elders that has a timeless, attractive design

aesthetic while being appealing and non-stigmatizing to the greater population within their communities.

Stigmas are huge reasons for resisting the use of an assistive device.

People who have need for AT use will more than likely use it all day and in the presence of others. A healthy self-image is important to any and all people. Users of an assistive device connect the device as part of who they are (Ferne, 1997). Cooper notes that making assistive devices as unobtrusive as possible is a good means to reduce the potential of the technology detracting from the person. Devices can be made small to make them more transparent or, with larger devices, the device itself can become a reflection of the user's persona. It is particularly important that a wheelchair is attractive to the user and integrates well into their lives to truly make it an extension of the user in form and function (Cooper, 1995).

Ferne's design model can also be applied to the marketing and sales of AT. If assistive devices can reach regular mass-marketing environments like chain stores and retail outlets, it would be a boon for the industry. If pieces of assistive equipment are designed to have features that reduce or eliminate the need for expert sizing and setup, they can attain much lower price points via high-volume marketing. (Ferne, 1997). It could be a

paradigm shift in the way that people buy assistive devices like wheelchairs and a form of empowerment for elders.

CHAPTER 4: DEVELOPING DESIGN CRITERIA

Though the R2b findings and literature review provided us with an extensive set of design implications, we needed to first take a closer look at how these implications could be turned into criteria for a wheelchair design. After determining this first set of criteria, we performed further research inquiries into ANSI/RESNA wheelchair standards and “K Codes” (the Medicare standards for determining wheelchair functionality based on user needs). This allowed us to determine further design criteria pertaining to wheelchair maneuverability, construction, safety, functionality and procurement.

Design Criteria: Elder Wheelchair Development Project (D2)

- 1) The retail cost of the wheelchair will be at or under \$400. (This represents the highest amount that most NH administrators will pay for a wheelchair.)

- 2) The wheelchair will better accommodate individuals who propel with their hands, feet or a combination of both. (It was found in R2b that 34% of elders use their hands-only to propel, 18% used their feet only, and users

that propelled using combinations of hand and foot motions represented 48% of this user population.)

3) The wheelchair's human factors will be designed primarily for the user, but must also accommodate an attendant (pusher).

4) The wheelchair will allow for folding.

5) The front casters will be placed to reduce the interference with the users' feet and ankles during propulsion.

6) The overall length of the wheelchair will be less than 38".to improve maneuvering in tight spaces. This criteria is based on review of typical K001 wheelchairs and finding difficulty in passing ANSI/RESNA Standard tests for turning radius and turns in place.

7) Maintain a maximum base of support (wheelbase) for the wheelchair to be at or less than 19 inches. (Nineteen inches is the typical length for the base of support found on most K0001 wheelchairs.)

8) The wheel track (width) of the wheelchair will be comparable to a current K0001 chair (21.5" -21.75".)

9) The weight of the wheelchair will be between 29 and 34 lbs (making it the same weight or lighter than most K0001 chairs).

10) The wheelchair will be equal to the static stability of a current K0001 chair.

11) Items that the user needs to operate (e.g. brake levers, footrest levers) will be accentuated or improved to ease use.

11) Due to its features, the wheelchair will be listed under the K0003 code - yet the cost will fall under the K0001 reimbursement rate.

“Nice to have . . .” Ideas:

A. The R2b findings and literature review also provided additional food for thought to benefit elder wheelchair users. Our team recorded, discovered, and brainstormed many great ideas, but some are potentially cost prohibitive. The following is a list of design team selected concepts that would prove useful in meeting elder wheelchair user needs to the fullest.

- B. An integrated seating system to the WC frame to improve posture and pressure relief for long term seating. (This may be a retrofit part designed for this wheelchair or it can be purchased as an option at initial purchase.)
- C. Adjustable footrest length to better accommodate different leg lengths and flexibility needs.
- D. Adjustable seat height to ease wheelchair ingress and egress.
- E. Adjustable seat height for standard and hemi height users.
- F. Add-on storage to secure foley bag and oxygen tank (out of the way and unseen) or to hold personal items.
- G. Push rims with increased size, larger than typical 50mm diameter (based on anthropometric data for hand grip size and designing for arthritis criteria). (3 Rivers Products "Natural Fit" Pushrim meets these needs quite well).

CHAPTER 5: HYPOTHESIS

Hypothesis

Based on the results of research participant observation and Literature Review, we began to find that the design of K0001 wheelchairs is restrictive to elder freedom of movement. Age related factors like losing range of motion in the shoulder, muscle atrophy and kyphosis make it difficult for elders to reach back to the wheels on this type of wheelchair. In addition, the long wheelbase of a K0001 wheelchair makes it difficult to maneuver. We believe that a wheelchair featuring a mid-wheel design (drive wheels beneath the center of gravity) will enable elders to perform activities of daily living, (ADLs) with greater ease than a standard 'depot'-type wheelchair by enabling more efficient propulsion and adding maneuverability.

Null Hypothesis

The null hypothesis to this belief is that no difference in ADL performance between an elder that is using a mid-wheel drive wheelchair and a standard 'depot'-type wheelchair.

CHAPTER 6: RESEARCH AND DEVELOPMENT

Goals and Objectives

In this project, the general goal was to develop a better means of mobility and comfortable, supportive seating for elders in ALF, NH, and AIP than a standard wheelchair. The specific objectives of the project were to design a wheelchair that meets the varied needs of elder WC users, caregivers and facility staff of NH and ALF based on synthesizing the needs data and design criteria identified in R2b and our early D2 research; test prototype technology with elder users as it was developed; and to seek commercialization of the technology (Bernard, R. et al. 2004.)

Research Design

Research Question

How does the gross movement of the main drive wheel of a wheelchair affect the hand and foot propulsion of an elderly user?

Phase 1: Elder Propulsion Methods Study

The purpose of this study was to investigate the effects of gross movement of the main drive wheel of a manual wheelchair on elderly users who propel with their hands, feet, or a combination of both hands and feet. We wanted to see how these changes in drive wheel position affected elders independent mobility.



Fig 7. Randy Bernard talking with a participant during our first round ADL study

We are evaluating three different drive wheel location designs. Our study is looking at three gross drive axle changes to determine how wheel

location affects functionality We looked at the ability of the elders to complete specific ADL activities, their range of motion, efficiency, effectiveness, and comfort across the three different wheel positions.

Methods

A total of 21-35 subjects 65 to 90 years of age who use a manual wheelchair as their main mode of transportation participated in the study. All participants were asked to propel independently on indoor surfaces. The participants were recruited at Atlanta area nursing homes (NH), and assistive living facilities (ALF). We accepted a variety of users into the study spanning from arm propellers -using their hands to propel, leg propelling group -using both of their feet to propel on the floor, and combination propellers -who use both hands and feet during wheelchair propulsion. We were also fortunate enough to recruit participants of all possible races and genders, adding to the diversity of our participant base for this study.

Recruiting Procedures

We recruited participants living in the Atlanta area who are residents of local assistive living facilities and nursing homes. Our specific exclusion criteria included persons who 1) have a spinal cord injury; 2) had an arm

or leg amputation; 3) are to propel their wheelchair with their arms and legs; 4) are severely cognitively impaired; 5) had recent back problems or surgery; 6) are unable to speak English; and/or 7) unable to follow directions.

Due to limitations in test equipment -the use of basic, rigid frame wheelchairs, we recruited only users who could propel bilaterally with both hands and feet.

All participants signed a consent form to indicating their voluntary participation. Basic information including age, gender, body height/weight was recorded before the experiment with each participant. We also conducted a basic ADL evaluation study with each participant to determine the abilities of elderly individuals concerning propulsion of manual wheelchairs with their hands and/or feet.

Cognitive/Psychological Factors

All subjects were assessed by the research staff using the Folstein Mini-Mental State Examination (Joray S, Wietlisbach V, Bula CJ, 2004).

Participants with an MMSE score of 24 and higher were be used for the study. In some cases, individuals with scores of 21-23 were further evaluated, to determine if they can follow directions and complete the

study. This will was accomplished by asking the individual to perform simple tasks, if they were capable of both following verbal instructions and maintaining focus for the duration of the task, they were included in the study.

Experimental Procedure & Wheelchair Setup

The experimental procedure included 1) signing an approved consent form from the Georgia Tech and Georgia State University Institutional Research Boards, for human subject testing, 2) measuring body weight, hip width, popliteal height, seat depth, sitting height, upper arm length, forearm length, and hand length.

We used 3 Sunrise Medical Zippy GS 16"-18" adjustable width wheelchairs. One wheelchair was configured for rear wheel drive(drive wheels behind the user/machine COG)(see Figure 8). A second chair was prepared in a mid-wheel drive configuration (drive wheels beneath the user/machine COG)(see Figure 8). (Design Note: the mid-wheel drive chair required the use of an additional rear caster(s) to balance the chair and reduce tipping. A 5 wheel design was used for all ADL and kinematic testing.) The final chair was a front wheel drive setup (drive wheels in front of the user/machine COG) (see Figure 8). All wheelchairs were fitted with anti-

tips or other safety devices to reduce the risk of falls or injury during the study.



Fig 8. Rear Wheel Drive Config.



Mid-Wheel Drive Config.



Front Wheel Drive Config.

One day prior to testing, each participant was measured and fitted for the test wheelchairs. We then adjusted the test wheelchairs to fit each user for testing. Seat height, depth, and width were adjusted for each participant in the study. For arm propulsion we adjusted the seat height so when the users hands are at 12:00 on the drive wheel, their arms are at 60° to 80° of flexion (Aissaoui R, Et al, 2002). (This positioning technique has been used on numerous research projects to be the optimal amount of arm flexion for propulsion.) For leg and combo propulsion the seat to floor height will be adjusted for each user to maintain correct seating posture while allowing sufficient leg clearance for propulsion.

Wheelchair Skills Test – ADL Testing

We chose the Wheelchair Skills Test (Kirby, Dupuis, Macphee, et al, 2004) to evaluate the ADL performance of each participant. The wheelchair

skills test is broken into three categories; basic, intermediate, and advanced. For our test we only required the participants to perform some of the basic skills and two of the intermediate skills. The basic skills included: level locomotion (roll forward/backward), turns in place, moving turns, turns 3-point, parallel parking, and door (open away/towards object). These tests were selected out of the list based on the ADL activities that we were trying to evaluate during the testing.

The Wheelchair Skills Test (WST) was designed to determine if a participant is capable to complete the activity safely, it's intent is not to rate how well or easy it was completed. For our test we not only wanted to determine if the participant can completed the task, but how difficult was it for them to complete the activity with different equipment setups. We tracked their task performance in two ways to increase the granularity of the information that we acquired for each user.

In order to increase the number of potential participants we conducted the ADL portion of the study at the facility the resident lives. The WST was designed to be run either in a dedicated location or in outside locations. We set up the test location prior to the start of the study with the necessary equipment in a large flat area found in places like the dining areas, hallways, and common rooms found in most NHs and ALFs.

We asked each participant, prior to starting the ADL study, to rate their pain during propulsion, location of pain, and ease of propulsion in their current wheelchair. To measure pain we used the Numeric Pain Rating Scale. We then asked the participant the location of the pain. To determine the users perception of which wheelchair was more maneuverable, we used a similar numeric scale. After each participant completed the ADL tasks with each of the test wheelchairs we asked each participant questions about the maneuverability of each chair. Following this, they were asked again to rate their pain(s) associated with wheelchair usage and its location. After all 3 wheelchairs were tested, we asked the participant which of the three wheelchairs they preferred and why.

Data Collection

The first method of data collection involved timing the participant during each ADL task with each drive wheel configuration. The second method asked the participants a series of questions, after they had completed all of the tasks with all three wheel configurations, to find out which wheel orientation was easier to maneuver, which one was most difficult, and to gather any additional insight on the designs. We then analyzed the participants responses with the times collected and determine if there is a

correlation between the three data points. We then used these findings to help us further define the Wheelchair Skills Test for our specific needs concerning the elderly population.

Test Setup

Prior to the start of the test we randomized the order test wheelchairs. Each participant was only required to perform the skills with their current method of propulsion. Each participant was required to perform the 7 wheelchair skills 3 times, one time per axle position. At the end of each test the participant was allowed to rest for approximately 5 minutes. After the participant had completed all 7 tasks in the chair, they were asked their opinion on the chair performance, ease of propulsion, maneuverability, and preference. The participant was then asked to continue the test until all three sessions were completed or until they opted to stop due to fatigue. We timed each participant's set of tasks in each of the differently configured test wheelchairs. After all three wheel configurations were tested, the participant was asked additional questions on which wheelchair they preferred and why they preferred that wheelchair.

Kinematics and Force Study

Wheelchair propulsion has been extensively studied in kinematics in terms of cycle time, ratio of the drive and recovery phase, and velocity pattern (Sanderson, & Sommer, 1985; Wang, Beale, & Moeinzadeh, 1996; Wang, Deutsch, Morse, Hedrick, & Millikan, 1995). However, the kinetics of wheelchair propulsion in terms of joint reaction force and muscle moments has not been well-documented since the measurements of 3-D forces and moments during wheelchair propulsion is a challenge task (Boninger, Cooper, Robertson & Shimada, 1997). The biomechanical effects of the main drive wheel at different positions on kinematics and kinetics have not been investigated. Therefore, the purpose of this portion of our study was to investigate the effects of the various propulsive techniques (using arms, legs, or combination propulsion) to wheel the main drive wheels of 3 differently configured wheelchairs (drive wheels in three different positions) on the range of motion, efficiency, effectiveness and comfort among the elderly users.

We then tested the participants wheelchair propulsion using their chosen method of propulsion (arm, leg, or combination propulsion) on the three aforementioned test wheelchairs at two speeds (the maximum effort speed, and a self-comfortable speed) via two wheelchair skills (straight

forward rolling and turning rolling) to evaluate the comfort of usage of each wheelchair setup (front, mid, or rear mounted drive wheels) during wheelchair propulsion.

Test Setup

The sitting trunk height, upper arm length, forearm length and hand length were measured by a physical therapist using a standard anthropometrical testing kit. These measurements were matched to landmarks used for the 3-D filming process in the calculation of linear angular velocities (speeds), 3-D forces, and the ratios of velocities to forces. The actual data collection procedure of wheelchair propulsion was then initiated. Eight reflected marks were used in the wheelchair model to identify the motion of the defined segments. These markers were placed on the fifth metacarpal head, styloid process, lateral epicondyle of the humerus, acromion, greater trochanter (in the dominant side), the forehead, wheel hub, and pushrim for arm wheeling group. For leg wheeling group, markers are placed on the fifth toe, lateral malleolus, lateral center of knee joint, greater trochanter (in the dominant side), acromion, the forehead, wheel hub, and pushrim.

After a 10-minute warm up of upper extremities, the participants were helped into the 3 differently configured test wheelchairs. A CatEye speed

meter was be used to monitor the speed of wheelchairs. Once the subject reached the target speed ($\pm 2\%$), for arm and combination propellers, a ProReflex imaging system, JR3 force measuring system, and Burtec force platform system recorded the propulsive movements for seven seconds. Two trials were recorded at 100 Hz on each speed condition. The whole lasted approximately 60 to 90 minutes for each participant.

Variables in Data Collection

Variables in data collection involved anthropometrical data such as body weight, sitting height, upper arm length, forearm length and hand length.

The independent variables surrounded the three test wheelchairs with different main drive wheel positions and the two paths (straight and curved) used in the kinematics study. Dependent variables included kinematical variables, kinetic variables and elders' scores concerning comfortable use of these three wheelchairs.

The kinematical parameters concerned these factors: 1) Linear and angular ranges of motion of the wrist, elbow and shoulder for arm wheeling, linear and angular ranges of motion of the ankle and knee for the leg wheeling, 2) Linear and angular velocities of center of mass of the

hand, forearm and upper arm for arm wheeling, linear and angular velocities for the ankle and knee for the leg wheeling, 3) Hand initial contact angles and release angles for arm wheeling, 4) Arm and leg wheeling frequencies and coasting distances from a stroke of arm wheeling and leg wheeling.

Kinetic parameters involved: 3-D Joint reaction forces and moment measured from the pushrim and the joint reaction forces and muscle moments at the wrist, elbow and shoulder joints for arm wheeling, and the joint reaction forces and muscle moments at the ankle and knee joints for leg wheeling.

Phase 2: Data Analysis – Elder Propulsion Study

A 3 x 2 (three wheelchairs x two skills) repeated measurement ANOVA (Green, Salkind, & Akey, 2000) were used to determine the difference between the three types of wheelchair across two paths. Independent testing was employed to examine the difference between the two groups via contracted outside statisticians. The 3-D filming data was automatically digitized, then smoothed and normalized along with the 3-D kinetic data. The results of the users effort was used to interpret the effectiveness of wheelchair propulsion between the three

aforementioned wheelchairs and two paths. The results of velocity/force ratios was used to determine the maximum forces that elders could output to each wheelchair type. These tests enabled us to determine which wheelchair type(s) have distinct advantages for elder users.

The analysis found that elders could exert greater peak forces to the drive wheel with the mid-drive wheelchair than with the other 2 chairs. This supported our hypothesis and the results from the Elder ADL study. Further results are still being analyzed by Dr. Tai Wang of Georgia State University. A paper will be released later this year in entitled "Kinetic Analysis of Three Different Drive-Axis Wheelchairs Propelled by Elderly with Arms and Legs" it has been accepted for presentation as a poster session at the 53rd Annual Meeting of the American College of Sports Medicine on May 31, 2006.

Data Analysis - Elder ADL Study

The first round analyses of the ADL testing illustrated proof-of-hypothesis and allowed us to move forward with developing a mid-drive wheelchair. The ADL testing showed that the mid-drive manual wheelchair in our study showed definite advantages for our elder users in terms of both maneuverability and propulsion across all the wheelchair types tested (Hayter, 2005) (See Table 2).

Table 2. Summary of Data used in Analysis of Elder ADL Study

Block	Treatment	Level Locomotion		Turn in place		Moving turns(Left)		3 point		Parallel		Door-away		Door-toward		Average
		Data	Rank	Data	Rank	Data	Rank	Data	Rank	Data	Rank	Data	Rank	Data	Rank	
P1	Current	7.84	1	9.195	2	34.31	2	24.13	1	20.815	4	26.02	2	141.71	*	2.0
	Front	27.89	4	12.795	4	83.14	4	38.33	4	18.17	2	115.79	4	*	*	3.7
	Middle	10.43	2	10.735	3	31.69	1	27.995	3	15.33	1	39.85	3	58.79	*	2.2
	Rear	12.44	3	7.42	1	36.44	3	24.86	2	20.27	3	25.98	1	147.56	*	2.2
P2	Current	26.42	4	35.365	3	35.81	2	39.54	3	47.03	4	57.58	2	134.25	3	3.0
	Front	18.15	3	12.3	1	53.52	4	66.85	4	23.69	2	62.06	3	255.14	4	2.8
	Middle	17.05	2	14.41	2	46.96	3	32.935	2	24.615	3	67.26	4	77.02	2	2.7
	Rear	16.89	1	68.39	4	31.44	1	32.445	1	21.57	1	57.42	1	71.28	1	1.5
P3	Current	12.29	3	5.485	2	20.23	3	24.16	4	8.72	2	16.28	2	35.13	3	2.7
	Front	13.43	4	6.72	4	25.63	4	21.58	3	8.735	3	23.51	4	85.33	4	3.7
	Middle	7.93	1	5.055	1	16.16	2	16.37	1	6.85	1	18.83	3	20.25	1	1.5
	Rear	11.54	2	5.545	3	14.04	1	20.73	2	10.205	4	14.55	1	22.7	2	2.2
P4	Current	5.87	1	2.66	2	11.06	1	17.82	3	29.34	3	17.44	3	22.57	3	2.2
	Front	9.13	3	8.49	4	39.24	4	35.62	4	31.995	4	28.78	4	30.57	4	3.8
	Middle	8.86	2	2.65	1	15.79	2	15.7	1	15.185	1	12.9	1	20.38	2	1.3
	Rear	9.17	4	3.765	3	24.28	3	15.72	2	17.825	2	16.85	2	19.36	1	2.7
P5	Current	10.37	3	4.585	3	17.96	2	16.675	1	7.775	2	21.25	2	23.25	1	2.2
	Front	12.88	4	6.8	4	30.88	4	25.095	4	34.58	4	30.41	4	37.16	4	4.0
	Middle	10.28	2	4.08	2	18.95	3	18.89	2	8.865	3	21.29	3	26.77	2	2.5
	Rear	9.03	1	3.79	1	15.62	1	21.385	3	5.95	1	18.94	1	28.02	3	1.3
P6	Current	10.45	2	33.64	3	*	*	27.735	2	17.93	3	64.16	4	125.97	4	2.8
	Front	10.6	3	21.785	2	36.02	*	39.11	4	21.89	4	26.16	1	69.69	3	2.8
	Middle	9.81	1	13.355	1	24.62	*	38.175	3	13.27	1	52.14	3	51.59	1	1.8
	Rear	12.5	4	50.34	4	*	*	19.795	1	13.94	2	29.83	2	55.03	2	2.6
P7	Current	6.02	1	4.99	3	15.27	3	12.705	1	5.66	2	10.43	2	18.93	2	2.0
	Front	37.81	4	6.475	4	28.18	4	18.68	4	14.14	4	32.18	4	27.98	3	4.0
	Middle	6.6	2	4.335	2	11.18	1	12.95	2	4.34	1	10.78	3	17.75	1	1.8
	Rear	6.87	3	3.905	1	12.01	2	15.16	3	7.225	3	10.23	1	33.5	4	2.2
P8	Current	11.63	4	4.44	1	24.12	2	18.2	2	10.76	2	21.7	3	47.41	3	2.3
	Front	10.25	3	7.805	4	31.45	4	19.68	3	9.81	1	14.11	1	29.36	2	2.7
	Middle	9.75	2	4.93	2	23.13	1	19.965	4	11.705	4	25.45	4	25.18	1	2.8
	Rear	8.95	1	6.135	3	25.91	3	17.63	1	11.23	3	16.82	2	47.88	4	2.2
P9	Current	14.32	4	11.62	4	25.66	1	27.96	2	15.82	3	57.52	4	120.36	1	3.0
	Front	13.71	3	11.575	3	32.59	4	28.185	3	16.21	4	42.37	3	147.88	3	3.3
	Middle	9.2	1	6.32	1	26.31	2	27.84	1	14.195	2	40.72	2	170.81	4	1.5
	Rear	9.52	2	8.235	2	28.98	3	43.33	4	14.01	1	36.31	1	142	2	2.2
Average	Current	2.6		2.6		2.0		2.1		2.8		2.7		2.5		2.5
	Front	3.4		3.3		4.0		3.7		3.1		3.1		3.4		3.4
	Middle	1.7		1.7		1.9		2.1		1.9		2.9		1.8		2.0
	Rear	2.3		2.4		2.1		2.1		2.2		1.3		2.4		2.1

Hayter 2005.

We also received qualitative data in the form of observations and comments that also proved useful in further developing the mid-drive manual wheelchair. Examples of this data include: 1.) The discovery that elders seem to have a more realistic perception of the volume of the mid-drive wheelchair. They had less frequent collisions with test objects like pylons and cardboard “walls” and solid objects like walls and door thresholds than in the other wheelchair types tested. 2.) There are limitations concerning the mid-mounted drive wheel for the small portion of elders who laterally transfer. 3.) It is difficult to find a good location for mounting standard wheel locks to a mid-drive type of configuration due to wheel placement. 4.) Problems with wheel bridging exist due to the use of front and rear casters on the mid-drive design. The drive wheels will lose contact with the ground when the front and rear casters encounter a sudden change in elevation (e.g. a ramp) -if they are rigidly mounted to the wheelchair.

A final data analysis is currently being conducted on the ADL data. This will be published in an article to be released later this year.

Phase 3: Early Product Development and Problem Solving

As the data for the ADL and kinematics studies is being analyzed further, in summer 2005, we began to take on the bridging problem that occurs with a 6-wheeled wheelchair. After months of brainstorming, I came up with an initial concept that links the front casters to the drive wheels via a simple swingarm (class 1 lever). We believed that this would solve our bridging problem by allowing the drive wheels to contact the ground at all times as terrain or angle changed, but did not allow for large obstacle clearance. We outfitted a Sunrise Zippie with this solution (this became our first round prototype) and put this idea through its paces for several days (see Figure 9).



Fig 9. Zippie w/Swingarm (Orig. -Fwd. Swingarm Config.)

After a team brainstorming session including Randy Bernard, Co-Director of the Mobility RERC, Ceara Byrne -our undergraduate assistant, and Jon Jowers -our Shop Technician, Jon came up with the idea of flipping the swingarm around and putting the casters in the back of the wheelchair. We now had a viable, simple, and elegant solution for bridging that allowed for easily clearing large obstacles and more stable propulsion. However, we needed to optimize that solution to make it work fluidly in relation to the wheelchair and a range of user types and sizes (see Figure 10).



Fig 10. Zippie w/Swingarm (2nd. -Rear Swingarm Config.)

Phase 4: Test Mule Development

Our next step involved building a test mule for weight distribution and further maneuverability testing. We used an Invacare EX2 due to its affordability and availability. We first extended the frame of the EX2 with aluminum tubing (to allow for front caster clearance). We then created a plate-type swingarm with a series of holes on 1" centers. This plate could

be attached to the chair in the same manner as the simple swingarm found on the first round prototype, but allowed us to have a wide range of pivot point and drive wheel mounting possibilities (See Figure 11).

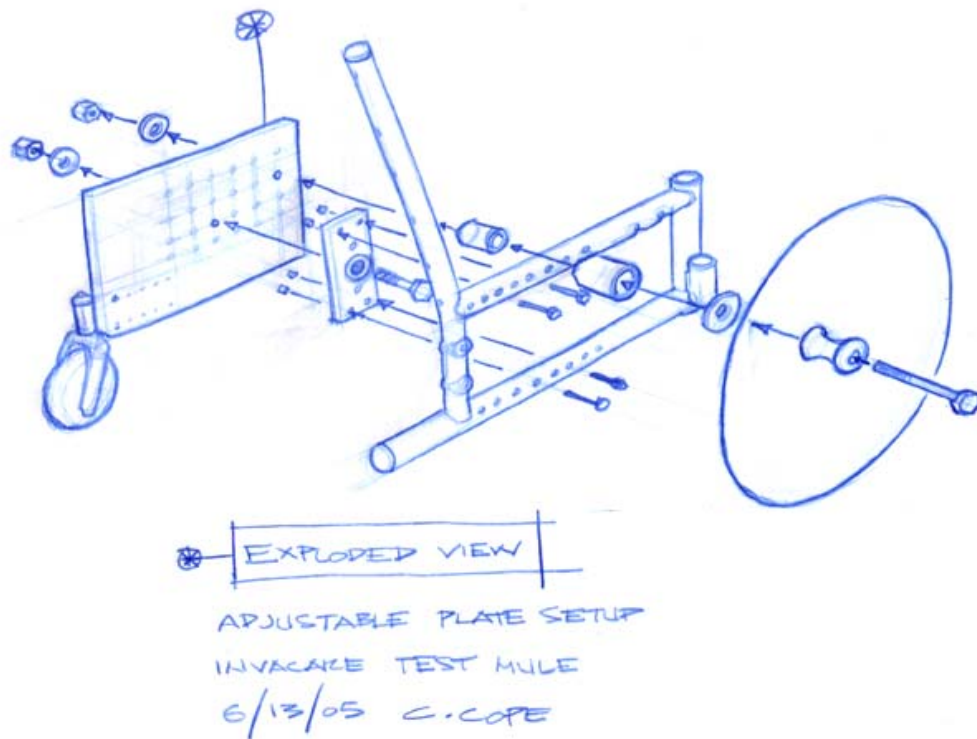


Fig 11. Swingarm Plate Setup (Exploded View)

Due to the fact that there are over 60 possible means of attaching the swingarm and mounting plate we created a key for the mounting plate location and swingarm. This would help to ease data collection and communication (See Figure 12).

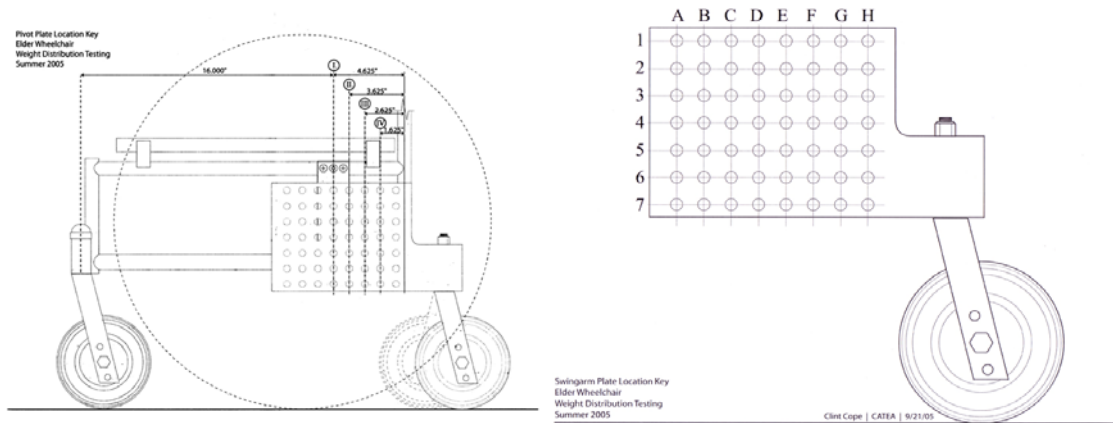


Fig 12. Mounting Plate Location Key

Swingarm Plate Location Key

We used this chair for further obstacle clearance testing and then tested how the weight distribution changes as pivot points and drive wheel locations change using a weight testing platform that places a scale beneath each wheel (Like a miniature truck weigh station). We tested the 40 viable solutions allowed by the test mule plate-type setup using a male participant with weight approximate to a 75th percentile male and female participant with weight approximate to a 50th percentile female (see Figure 13).



Fig 13. Test Mule 1 on weighing station

On further consultation with Dr. Steven Sprigle -Director of CATEA, concerning the analysis of the data, we found that we did not have statistically significant variance across the setups we tested that gave optimum traction (over 50% of the weight over the drive wheels). Therefore we could not select a swingarm setup using only the data acquired from the weight distribution testing. We opted to go with a second round of testing with 'able-bodied' participants from College of Architecture and CATEA that were unfamiliar with the wheelchair project to get unbiased feedback.

During our preparation for the next round of testing, Randy Bernard's efforts to court a corporate sponsor proved successful. In October 2006, Mr. Bernard and I were flown out to Longmont, CO to meet with Sunrise Medical about our work on the elder wheelchair. The meeting was a huge success. (A final partnership agreement is now in place as of March 2006). However, it changed the nature of the project in terms of scope. Our research into a better wheelchair for elders became the first step in a larger picture. Sunrise wants to create a multi-purpose wheelchair or wheelchair line that could meet the needs of a wider variety of wheelchair users, like spinal-cord injury (SCI) or multiple sclerosis (MS) wheelchair user populations. This reminded us that we needed to think of the broader scope of potential users as we continued our development of this wheelchair, but still remain true to our original project goals.

Phase 5: Test Mule (AB) User Research

Research Purpose

The purpose of our second round of research was to determine optimum pivot/drive wheel placement on a 6-wheeled wheelchair design. This study added further support for a basis of determining the ideal swingarm locations/types for wheelchair users.

Test Mule Refinement

Because our original test mule used a heavy plate for the swingarm, it added additional, unnecessary weight to our design. We designed and welded a second test mule using round cro-moly tubing for the frame and rectangular cro-moly tube swingarms. We then ran weight distribution tests using our previously noted 75th percentile male participant and a newly acquired ANSI/RESNA test dummy. We wanted to check for trends found in our previous weight distribution tests and to establish the ANSI/RESNA dummy as a future standard in weight distribution tests) (see Figure 14).



Fig 14. Test Mule 2

We tested these participants using 6 wheel and pivot point relationships that varied from each other while still representing sectors of the broad range of setups with optimum weight distribution that we discovered using the first round test mule testing. We created these 6 unique configurations using 3 different swingarm types and 2 mounting plate locations. This yielded a 3 x 2 format for our research protocol.

Testing Specifications

Participants (able-bodied) were asked to perform 4 tasks in a wheelchair (or 1 set of tasks) in a provided standard wheelchair, a Sunrise Breezy Ultra 4-(a commonly used/prescribed K003 wheelchair) and our 6 wheeled experimental wheelchairs with various swingarms. Each participant tested the 6 wheeled wheelchair in 4 different swingarm positions for a total of 5 sets of tasks/participant.

3 different types of swingarm shapes were used for this study . The swingarms were mounted to 2 different mounting plate locations, one at the rear of the chair (Position 1) and one under the chair/user system center of gravity (Position 2)(see Figure 15). It was hoped that based on the swingarm/mounting plate relationship, we would find variance in the handling characteristics of the wheelchair when traversing an obstacle. However, this was not assumed.

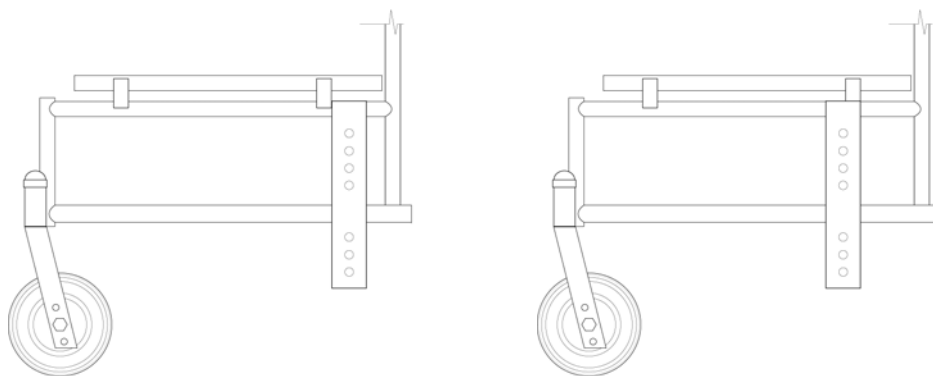
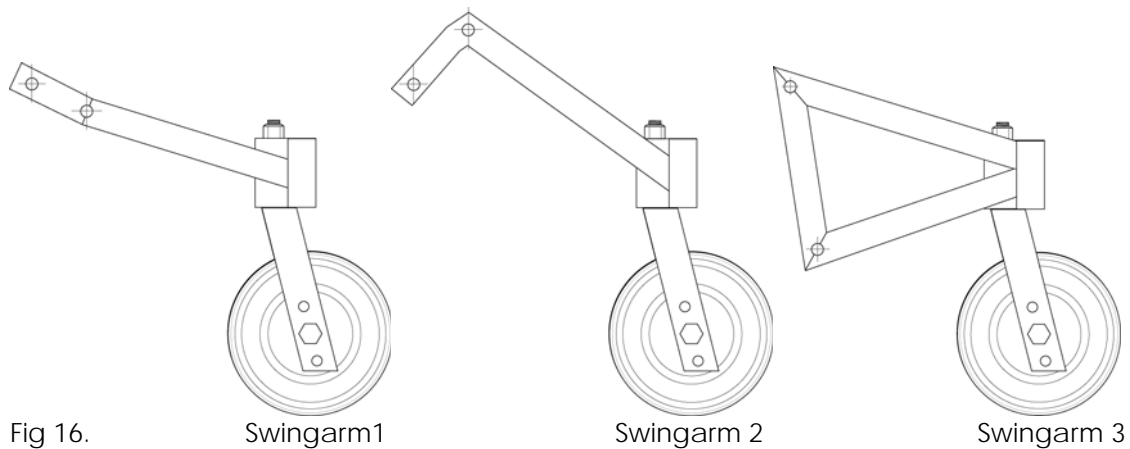


Fig 15. Mounting Plate (Position 1)

Mounting Plate (Position 2)

The 3 swingarm shapes vary. The first shape (referred to as 'Shape 1') is a class 1 lever in which the pivot point is parallel to the wheelchair's drive wheel axle (see Figure 16). The second shape (referred to as 'Shape 2') is a class 1 lever in which the pivot point is above the drive wheel axle (see Figure 16). The third and final shape (referred to as 'Shape 3') is a class 1 lever in which the pivot point is below the drive wheel axle (see Figure 16).



As noted above, we were working with participants from an able bodied population for the study. We utilized the services of 15 members of this population of varying ages. (Total study population = 15 people). All participants used arm propulsion for all of the test procedures. This allowed us to collect 10 full sets of data for each chair configuration.

Each participant first completed a set of tasks in a standard wheelchair (a Breezy Ultra 4). This acted as a base of comparison for the last 4 tests in the experimental, 6 wheeled wheelchair.

The participants then completed the same tasks that they performed in the standard wheelchair while testing the various swingarm positions in the 6 wheeled wheelchair. Participants were randomly assigned 4 different swingarm positions (out of a possible 6 selected positions) to reduce order effects. Overlap between test positions existed to ensure generalizability and to aid in later validation of results.

After completing each task, the participants characterized the ease or difficulty of performing a task involving each swingarm setup of the 6 wheeled wheelchair compared to the standard wheelchair (Breezy). The participants attempted a non-comparative test (named later in the protocol). Feedback/data acquisition was gained via the participant answering questions concerning each wheelchair task based on a 1-6 Likert scale. A 1-6 scale is used throughout the research to ensure acceptable granularity while not enabling participant or researcher to show complete apathy in judgment.

Tasks

1) Obstacle Clearance: Tasks 2A, 2B, 2C, & 2D

Test Setup: Tasks 2A, 2B, 2C,

Research team set up the test course on flat linoleum surface at the test facility. This test course was created by constructing a 76mm x 19mm x 1000mm long door threshold with 45mm beveled edges across the longest dimension of the shortest side at a 12mm depth. The team then affixed the door threshold to the floor with 50mm width gaffer's tape (or duct tape).

Test Procedure: Task 2A – Forward Obstacle Negotiation- Front Casters

The research team positioned the participant in a wheelchair with the front casters butted up against the 1000mm side of the door threshold. The moderator instructed the user to concentrate on how hard or easy it is to get the front casters over the obstacle. When the moderator said "Go" the participant was to push the wheelchair over the obstacle. The test ended when the wheelchair completely crossed the obstacle.

The test was graded by the moderator as pass/fail.

The participant failed if he or she could not successfully push the wheelchair completely over the obstacle.

The moderator then asked the user a post test question after completion of this task.

Question:

- *On a scale from 1-6, 1 being easy and 6 being difficult, how was it to get the front casters over the obstacle compared to the standard wheelchair (Breezy)?*

Test Procedure: Task 2B – Forward Obstacle Negotiation- Drive Wheels

The research team positioned the participant in a wheelchair with the drive wheels butted up against the 1000mm side of the door threshold.

The moderator instructed the user to concentrate on how hard or easy it is to get the drive wheels over the obstacle. When the moderator says “Go” the participant was to push the wheelchair over the obstacle. The test ended when the wheelchair completely crosses the obstacle.

The test was graded by the moderator as pass/fail.

The participant failed if he or she could not successfully push the wheelchair completely over the obstacle.

The moderator then asked the user a post test question after completion of this task.

Question:

- *On a scale from 1-6, 1 being easy and 6 being difficult, how was it to get the drive wheels over the obstacle compared to the standard wheelchair (Breezy)?*

Test Procedure: Task 2C – Reverse Obstacle Negotiation- Drive Wheels

The research team turned the wheelchair around and positioned the participant in a wheelchair with the drive wheels butted up against the 1000mm side of the door threshold. The participant was positioned facing away from the obstacle. The moderator instructed the user to concentrate on how hard or easy it is to get the drive wheels over the obstacle when backing-up over the obstacle. When the moderator said "Go" the participant was to push the wheelchair over the obstacle. The test ended when the wheelchair completely crosses the obstacle.

The test was graded by the moderator as pass/fail and also received a numeric score based on perceived user comfort and ability.

The participant failed if he or she could not successfully push the wheelchair completely over the obstacle.

The moderator then asked the user a post test question after completion of this task.

Question:

- *On a scale from 1-6, 1 being easy and 6 being difficult, how was it to get the drive wheels over the obstacle when traveling in reverse compared to the standard wheelchair (Breezy)?*

Test Procedure: Task 2D -Reverse Obstacle Negotiation- Rear Casters

(The standard wheelchair used in this protocol is excluded from this test due to lack of rear casters. Therefore, this was a non-comparative test.)

The research team turned the wheelchair around and positioned the participant in a wheelchair with the rear casters butted up against the 1000mm side of the door threshold. The participant was facing away from

the obstacle. The moderator instructed the user to concentrate on how hard or easy it was to get the rear casters over the obstacle when backing-up over the obstacle. When the moderator said "Go" the participant was to push the wheelchair over the obstacle. The test ended when the wheelchair completely crossed the obstacle.

The test was graded by the moderator as pass/fail.

The participant failed if he or she could not successfully push the wheelchair completely over the obstacle.

The moderator then asked the user a post test question if they were able to complete this task.

Question:

- *On a scale from 1-6, 1 being easy and 6 being difficult, how was it to get the rear casters over the obstacle when traveling in reverse?*

Test Procedure: Informal Inquiry

After each set of tasks was complete in each experimental wheelchair configuration, the moderator asked the following question:

- *Do you have any general observations about how this experimental chair compared to the standard wheelchair?*

Test Procedure: Follow-Up Questions

After all tests/tasks are completed, the moderator asked the participant two final questions:

1) Out of all the chairs that you tested today, what was your favorite? . . . Why?

2) Out of all the chairs that you tested today, what was your least favorite? . . .

Why?

The results from the informal inquiry and follow-up questions were collected and classified in a data table based on the swingarm being tested. At times, participants drew comparisons between experimental configurations or made general comments about the experimental chairs. These were also collected and classified based on the comment type and/or chairs being referenced.

Phase 6: Test Mule (AB) User Research Data Analysis

Preliminary Analysis:

Preliminary analysis of the data gained from the able-bodied (AB) user study involved breaking down the experimental wheelchair into the constituent parts that make up the swingarm system for the wheelchair. These parts are the mounting plate and the swingarm.

Because we had 6 experimental configurations to test, we opted to limit the number of chairs that each participant would test to 4 per user. This required using non-traditional, independent analysis methods because the participants do not serve as their own controls across all comparisons. Though possible errors can be generated by not using dependent analysis methods for comparing user feedback, there was also a high likelihood of errors in the raw data by requiring the participants to compare 6 wheelchair configurations. The participants validated this belief. The amount of cognitive load required to adequately compare 4 wheelchairs against the baseline wheelchair taxed most of the AB users. The process required concentration and frequent comparisons to the baseline wheelchair – a time consuming process requiring sometimes delicate and subtle elements of memory.

To compare the mounting plate locations, a Kruskal-Wallis analysis was run. We corroborated these findings by running a Wilcoxon signed ranks test, a form of dependent analysis, across select sections of users that used the same configurations.

These analyses revealed that mounting plate position 2 was easier than mounting plate position 1 when it came to pushing the front casters over an obstacle when traveling forward . They also found that mounting plate location 1 was easier than mounting plate position 2 when pushing the drive wheels over the obstacle when traveling forward. However, when pushing the drive wheels over an obstacle in reverse, no reportable difference could be found.

Kruskal-Wallis analysis was also used to compare the swingarms. A Mann-Whitney analysis was run to validate and further differentiate the findings of the Mann-Whitney analysis.

These analyses showed that Swingarm 1 was not different than Swingarm 2 or Swingarm 3 when pushing the front casters over an obstacle. When pushing the drive wheels over an obstacle, Swingarm 1 was harder to push over an obstacle than Swingarm 2, but easier to push than Swingarm

3. No reportable difference was found in pushing the drive wheels in reverse over an obstacle.

When pushing the front casters over an obstacle, Swingarm 2 tested as harder than Swingarm 3 to push the front casters over an obstacle, but not different than Swingarm 1.

When traveling forward, Swingarm 2 is easier than Swingarm 1 or Swingarm 3 to push the drive wheels over an obstacle. When pushing the drive wheels over an obstacle in reverse, Swingarm 2 tested as harder than Swingarm 3, but not different than Swingarm 1.

Swingarm 3 was shown as easier than Swingarm 2 as and harder than Swingarm 1 when pushing the front casters over an obstacle. Swingarm 3 tested as harder than Swingarms 1 and 2 to push the drive wheels over an obstacle when traveling forward. However, Swingarm 3 was shown as easier than Swingarm 2, but not different than 1 to push the drive wheels over an obstacle in reverse.

Mechanism Function

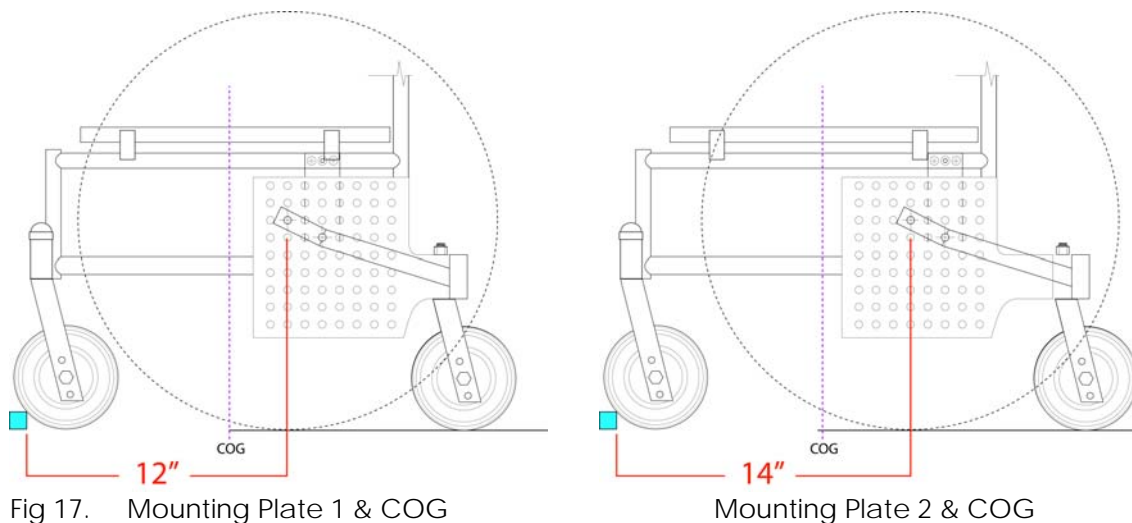
The preliminary analysis gave key insights into forming hypotheses on how this wheelchair system works. We then broke-down the wheelchair further based on this analysis to better determine how the wheelchair's swingarm system functions mechanically.

Mounting Plate Analysis

DWF: 1 easier than 2

DWR: no difference

Caster F: 2 easier than 1



Mounting plate Position 2 places the swingarm mounting plate further forward on the wheelchair (generally closer to the wheelchair/user system)

center of gravity). This eases front caster obstacle negotiation by bringing the swingarm pivot closer to the center of gravity -thus reducing the distance from the front caster to the drive wheel. This eases the user's ability to tip the chassis back to ease front caster clearance (see Figure 17).

Mounting plate Position 1 places the mounting plate toward the rear of the wheelchair. (generally further away from the wheelchair/user system center of gravity). This eases drive wheel negotiation by moving the swingarm pivot further away from the center of gravity -thus increasing the distance from the front caster to the drive wheel. This eases the user's ability to push over an obstacle with the drive wheels by reducing the ability of the chassis to tip backward (see Figure 17).

Swingarm Analysis

Swingarm #2

DWF: easier than #1 and #3

DWR: harder than #3, not different than #1

Caster F: harder than #3, not different than #1

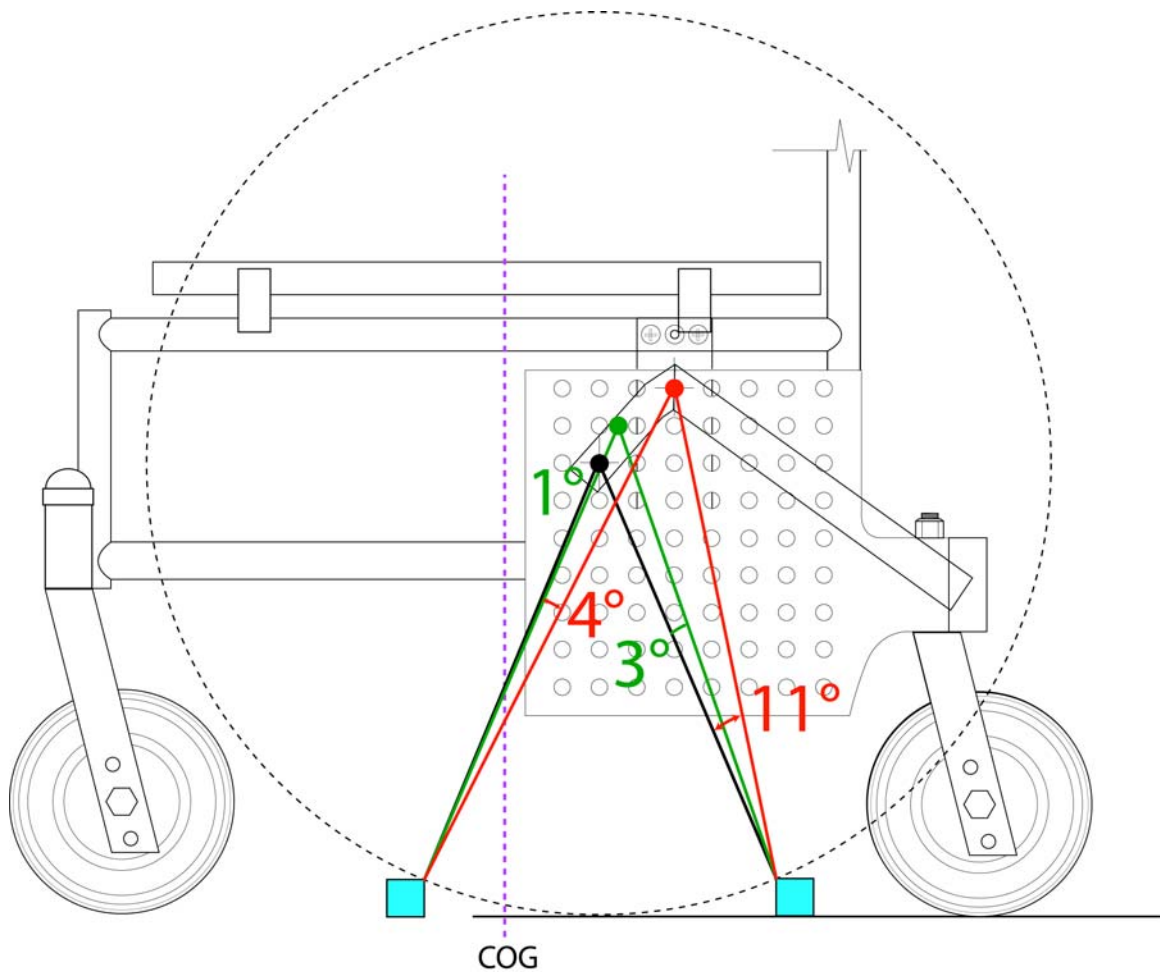


Fig 18. Swingarm 2 – Actual(Red) vs. Better(Green) Obstacle Climbing Angles

Swingarm 2 has the advantage of being able to climb over obstacles with ease when traveling forward. I believe that this advantage is explained by the relationship of the pivot point to the drive wheel center (see Figure 18). If you draw a chord from the pivot point (see red lines) and a radius from the center of the drive wheel (lever arm) (see black lines) to the fulcrum point of the wheel, one begins to see that the angle formed between the 2 lines is actually only a few degrees when going forward, but is nearly triple that when traveling in reverse.

After looking at the study results and video analysis, it is my belief that the lever arm forms a virtual stop or threshold for the system. When propelling over an obstacle, the swingarm actuates and attempts to 'lock-out' by aligning the chord with the radius –putting the pivot in-line with the lever arm. Because the lines are so close, they can come close to alignment quickly, 'lock out' the pivot system and move over an obstacle with ease when traveling forward. The system is also highly stable when traveling over an obstacle due to the close proximity to the system's vertical COG (generally near the seat).

Traveling in reverse with the drive wheels over an obstacle is another story. Because the pivot point of Swingarm 2 is so high, the chord-lever arm angle is 3-4 times the distance it would take to 'lock-out' the system when

moving forward over the obstacle. One might assume that backing up may be a more difficult endeavor. The system cannot 'lock-out,' stays dynamic, and forces the user to contend with 2 active pivot points while backing-up over an obstacle.

All the experimental configurations tested indicate similar or less effort than the baseline chair used in the testing (a Sunrise Medical Breezy). This indicates that one must also take the ratio of the front casters to the drive wheels into account. Because the relationship of the front casters to the drive wheel inverts (and actually increases due to the reversal of the caster forks) when traveling in reverse, all the experimental configurations tested as easier or comparable to push over an obstacle from a stop as the baseline chair. Swingarm 2 tested as comparable while Swingarm 3 tested as slightly easier (see factors why in next section).

The green chords and dot (see Figure 18) suggest a means to improve this configuration to ease both forward and reverse drive wheel negotiation by reducing the size of the angles. Because the pivot point drops by an inch and moves forward an inch and a half, the system requires using a rearward mounting location to stably push the drive wheels over an obstacle.

Swingarm 3

DWF: harder than #2 and #1

DWR: easier than #2, not different than #1

Caster F: easier than #2, not different than #1

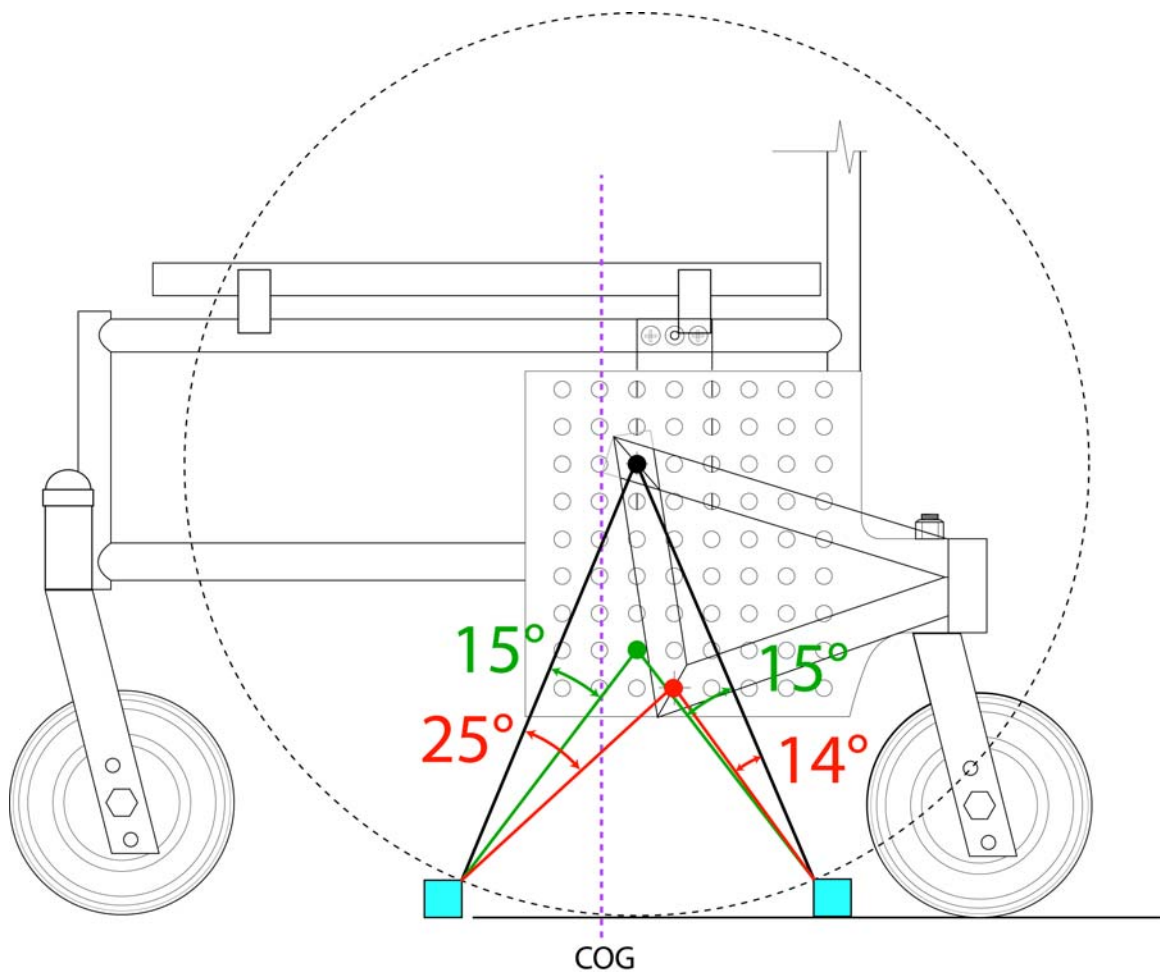


Fig 19. Swingarm 3 – Actual(Red) vs. Better(Green) Obstacle Climbing Angles

Swingarm 3 tested as the most difficult of the swingarms for forward obstacle climbing with the drive wheels. When you look at the chord-lever

arm angle, it puts this swingarm at a disadvantage for this particular task (see Figure 19).

Swingarm 3 has the advantage of being able to negotiate obstacles while traveling in reverse with the drive wheels with greater ease than Swingarm 2. I believe that this advantage is easily explained by having a roughly equivalent chord-lever arm angle combined with a lower pivot point than Swingarm 2.

When you look at the relationship of the chord-lever arm angle that Swingarm 3 has in comparison to Swingarm 2, the roles are reversed. Due to its low pivot point, Swingarm 3 moves in the opposite direction of Swingarm 2 when climbing over the obstacle in reverse. Though it cannot lock-out the system, the lower pivot point gives the swingarm better lifting ability by not requiring the swingarm to counter the force that is being exerted upon it by reverse propulsion.

This swingarm configuration also tested well for obstacle negotiation with the front casters. This is also due to its low pivot point. The increased distance from the seat/center of gravity in the Z axis allows it to tip-back over obstacles with ease. Because Swingarm 2 has a high pivot point, and is close to the COG, it creates a highly stable system –reducing the

ease of tipping-back the chair, but increasing effort for front caster negotiation.

The green chords and dot suggest (see Figure 19) suggest a means to improve this configuration to ease forward drive wheel negotiation by reducing this angle and raising the pivot point. This suggested configuration is unique because it places the pivot point beneath the drive wheel. However, to gain stability during normal propulsion, this suggested configuration requires moving the mounting plate backward. This puts the swingarm system further behind the wheelchair/user system COG.

Swingarm 1

DWF: harder than #2, easier than #3

DWR: not different than #2 and #3

Caster F: not different than #3 or #2

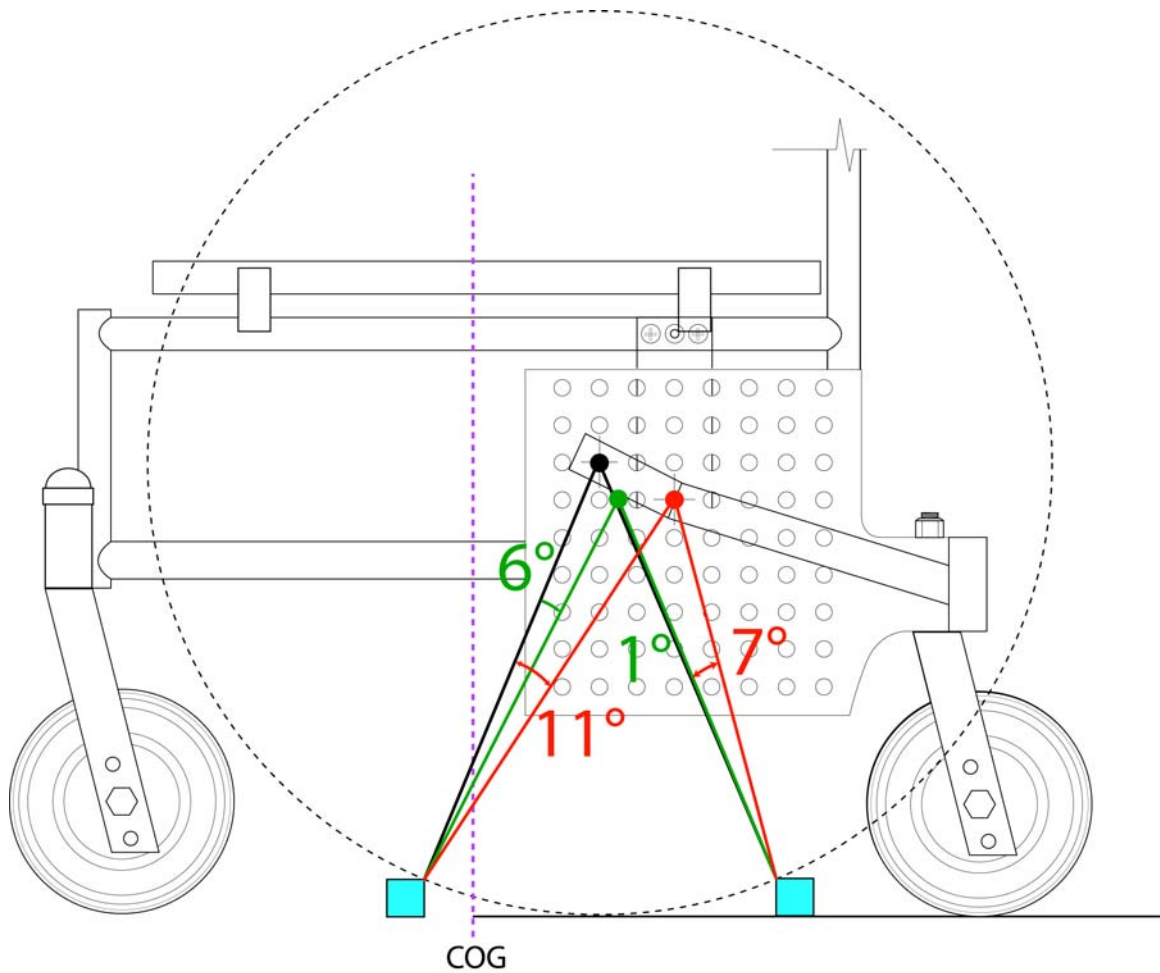


Fig 20. Swingarm 1 – Actual(Red) vs. Better(Green) Obstacle Climbing Angles

Swingarm 1 tested as the second most difficult of the swingarms for forward obstacle climbing with the drive wheels. When you look at the

chord-lever arm angle, it represents the middle ground between Swingarm 1 and Swingarm 3 (See Figure 20).

Though nothing can be conclusively stated at this point about whether or not Swingarm 1 can negotiate obstacles in reverse with the drive wheels any better or worse than Swingarm 2 or Swingarm 3, it does have a relatively short chord-lever arm angle. This suggests that it should be able to accomplish this task relatively well.

The green chords and dot suggest a means to possibly improve this configuration to ease both forward and reverse drive wheel negotiation by reducing the angles (See Figure 20).

Though the data analysis cannot conclusively state whether or not Swingarm 1 can ease negotiation of the front casters in a better or worse manner than Swingarm 2 or Swingarm 3, it does have pivot point height between Swingarm 2 and Swingarm 3. This suggests that it should be able to accomplish this task relatively well and in a slightly more stable manner than Swingarm 3.

Reverse Obstacle Negotiation: Rear Casters

All the configurations were not able to negotiate the obstacle from a stop when abutted to the obstacle. All the configurations could negotiate the obstacle when given a 6" rollup (or running start) to the obstacle.

The rear casters are not used for weight bearing but for stability. They do not need to bear a large portion of the wheelchair/user system's weight. Their only role is to stabilize the system due to the drive wheels close proximity to the wheelchair/user system's COG. This failure of the rear casters to overcome a small obstacle from a stop indicated that we needed to take a closer look at not only how the drive wheels and pivot point relate to an obstacle, but the rear casters and pivot point as well.

The same 'lock-out' / threshold angle rationale that is applied to the drive wheels can also be applied to the rear casters (see Figure 21). This indicates that a pivot points that are close to or lower than the drive wheel axle can aid in rear caster negotiation.

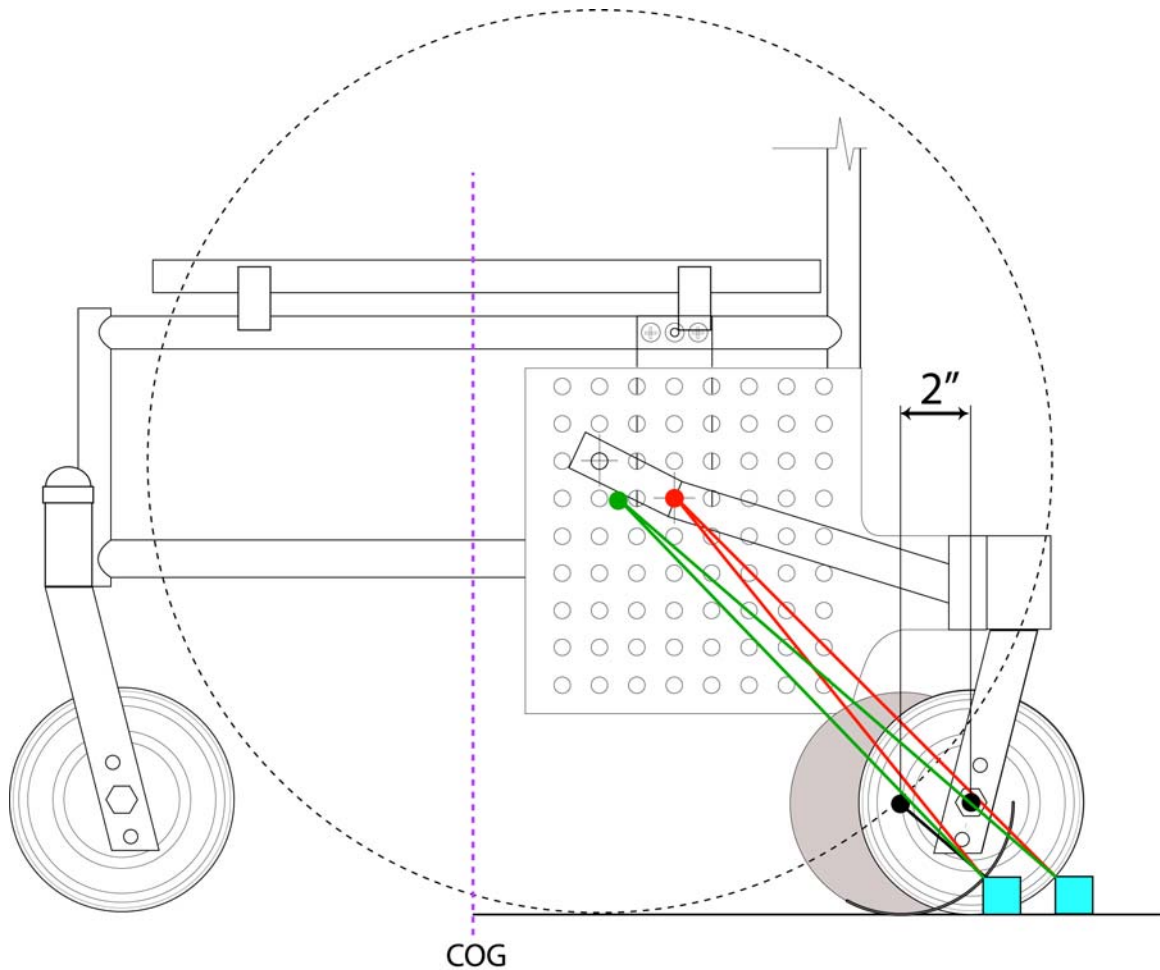


Fig 21. Swingarm 1 – Actual(Red) vs. Better(Green) Obstacle Climbing Angles (Rear Casters)

The suggested modifications (angles shown in green) and flipping around the caster housings to add 2" of length to the swingarms all decrease the length of the forward portion of the swingarm (drive wheel center to pivot point) while increasing the length of the rear portion of the swingarm (pivot point to rear caster). This new front to rear length ratio improves the lifting ability of the swingarm while traveling in reverse – easing rear caster negotiation of obstacles.

Comparing the Tested Configurations

After breaking apart the functions of the mounting plate location and swingarm types to determine a viable explanation as to how each swingarm configuration functions. I went back and applied this explanation to the results of a Kruskal Wallis analysis that was run on all the configurations. Figures 22-24 illustrate the configurations tested.

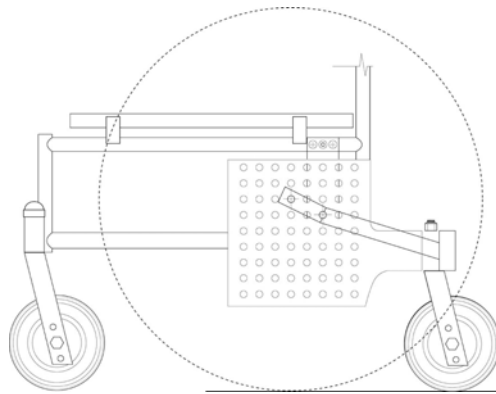
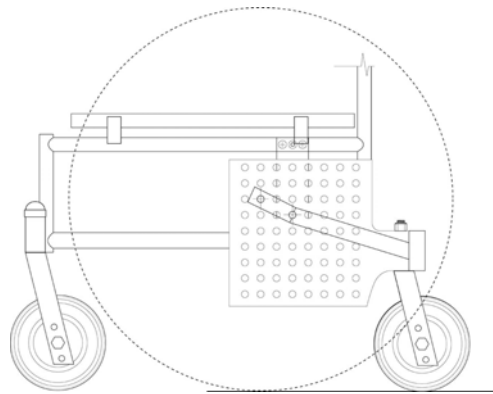


Fig 22. Swingarm Config 1.1



Swingarm Config 1.2

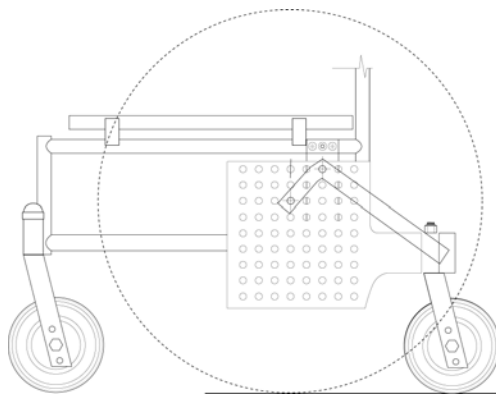
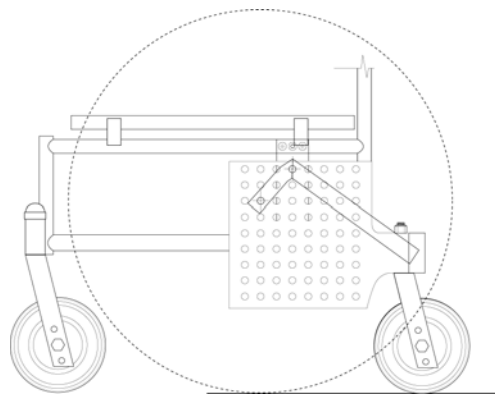


Fig 23. Swingarm Config 2.1



Swingarm Config 2.2

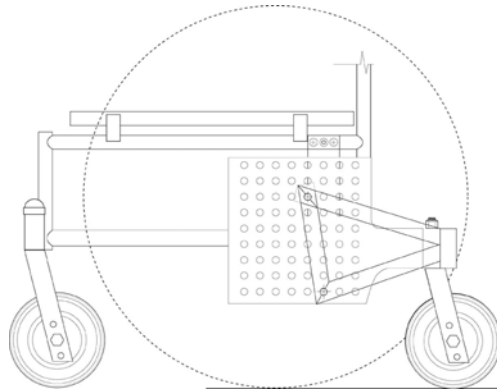
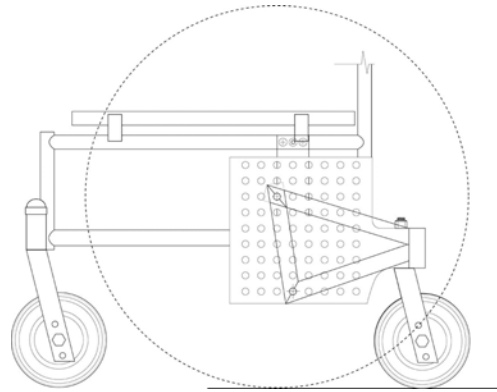


Fig 24. Swingarm Config 3.1



Swingarm Config 3.2

Front Casters and Obstacle Negotiation

When individual experimental wheelchair configurations' ability to negotiate an obstacle with the front casters were compared, it becomes apparent that 1.2 and 3.2 tested highest among the users and 1.1 and 2.1 tested the lowest for front caster negotiation. The forward mounting plate location caused the chair to tip-back easily during this task, giving 3.2 and 2.2 distinct advantages.

Drive Wheels and Forward Obstacle Negotiation

Upon comparing the individual experimental wheelchair configurations' ability to get over an obstacle while traveling forward, it becomes apparent that 2.1 tested highest among the users and 3.2 tested the

lowest for forward drive wheel negotiation. It is likely that the high center of gravity and forward mounting plate location of 3.2 caused the chair to tip-back during this task.

2.2 scored slightly lower than 2.1. Again, the forward mounting plate location is the likely culprit.

1.1 scored similarly to 2.2. Though Swingarm 1 may not possess the mechanical advantages of Swingarm 2 for forward drive wheel negotiation, the more rearward mounting plate location of configuration 1.1 helps to stabilize the chair during obstacle negotiation.

1.2 scored poorly for this task. Again, this is most likely due to mounting plate location.

3.1 scored second most poorly for this task. It's slightly more rearward mounting plate location was the likely reason for this.

Drive Wheels and Obstacle Negotiation in Reverse:

The Kruskal-Wallis analysis revealed no reportable differences in climbing the drive wheels over an obstacle in reverse. As mentioned previously, all the experimental configurations tested indicate similar or less effort than the baseline chair used in the testing (a Sunrise Medical Breezy). Because the relationship of the front casters to the drive wheel inverts (and actually increases due to the reversal of the caster forks) when traveling in reverse, all the experimental configurations tested as easier or comparable to push the drive wheels over an obstacle from a stop as the baseline chair – easing obstacle negotiation for even the widest ‘lock-out’ / threshold angles.

Assessment and Implications

Mounting Plate Position 2 eases front caster clearance. Mounting Plate Position 1 eases drive wheel clearance. Adjusting mounting plate location forward eases front caster clearance while rearward movement increases this effort. Moving the mounting plate backward adds stability to the wheelchair and decreases drive wheel obstacle negotiation effort.

(From the top pivot point locations the plate diagram) As you drop the pivot point of a swingarm design, the angles of interest (formed from drawing lines from the obstacle to the drive wheel and from the obstacle to the pivot point) increase for the angle of interest formed by an obstacle in front of the drive wheel.

(From the top of the pivot point locations the plate diagram) As you drop the pivot point, the angles of interest (formed from drawing lines from the obstacle to the drive wheel and from the obstacle to the pivot point) decrease for the angle of interest formed by an obstacle behind the drive wheel until the pivot point intersects the line between the drive wheel and the obstacle. The angle of interest then begins to increase as you move the pivot point below this point of intersection.

As the pivot point moves away from this point of intersection, it has less (or no) chance to 'lock-out' the system. However, though the angle of interest for an obstacle behind the drive wheel may increase, the lower pivot point gives these swingarms a different relationship to the system than those with pivot points above this point of intersection by creating a swingarm with an arc of movement that is broader than those provided by positions above this point of intersection. Swingarms with pivot points below this point of intersection no longer counteract the force that is

being exerted upon them by reverse propulsion. The swingarm can now 'go with the flow' instead of having to raise the wheelchair a great distance.

If you move the pivot point forward, you can decrease the angle of interest formed by an obstacle in front of the drive wheel and increase the angle formed by an obstacle behind the drive wheel. If you move the pivot point back, the reverse occurs.

Swingarm 2 negotiates obstacles well with the drive wheels when traveling forward. This indicates that when the pivot point is above the drive wheel axle and has a narrow 'lock-out' threshold angle, the drive wheels can travel forward over obstacles easily. The system is highly stable due to its close proximity to the vertical location of the COG (near the seat).

Swingarm 3 negotiates obstacles better than Swingarm 2 with the drive wheels when traveling in reverse and the front casters when traveling forward. This indicates that when the pivot point is below the drive wheel axle. It reduces the overall stability of the system, but eases front caster negotiation.

Swingarm 1 negotiates obstacles better than Swingarm 3 with the drive wheels when traveling forward. This indicates that Swingarm 1's higher pivot point makes for easier forward obstacle negotiation with the drive wheels than Swingarm 3 due to a higher level of stability than Swingarm 3.

Users could get the rear casters of all the wheelchair configurations over test obstacle (ADA threshold) with a 6" rollup. This actually tells us very little. But applying 'lock-out' / threshold angle rationale (that was applied to the drive wheels) to the rear casters gives us clues as to how to optimize the rear caster-pivot point relationship. This indicates that a pivot points that are close to or lower than the drive wheel axle can aid in rear caster negotiation (see Figure 20).

As mentioned earlier, the suggested swingarm modifications all decrease the length of the forward portion of the swingarm while increasing the length of the rear portion of the swingarm. This new front to rear length ratio improves the lifting ability of the swingarm while traveling in reverse – easing rear caster negotiation of obstacles.

After prototyping the suggested modified swingarms mentioned in this chapter, early indications from informal testing suggest that the behavior of the swingarms improves in front caster negotiation, stable negotiation

of the drive wheels, and easy rear caster negotiation of an ADA door threshold in reverse. The stability of the swingarm system can be adjusted based on mounting plate location – an easy way to change the swingarm system characteristics based on user preference or handling needs.

We're trying to find a sweet-spot where you're able to find a balance between pivot point height and pivot point location fore and aft (while still allowing the drive wheel to clear the front casters and keeping the swingarm length short enough to not exceed the length of a K0001 chair.

At this point, I think that the suggested change to swingarm 1 has yielded a swingarm that does just that.

Final Design Validation

The modified swingarms will be used for an elder cohort study of ADL activities to validate the findings of the AB study. The report from this upcoming study will be submitted to Sunrise Medical so that they may develop a better wheelchair for elders and other user populations. The data analysis and resultant prototype swingarms have yielded the following design recommendations for elder cohort study:

- We will drop Swingarm 3 from the Elder Cohort Study due to its inherent instability and difficulty in forward drive wheel negotiation. We will save this swingarm for testing the WC with other potential user populations.
- Because the suggested modifications move the pivot point forward, the swingarms will be mounted along the “Axle 1 location” or a compromise of the mounting plate positions (directly between the Axle 1 and Axle 2). This still eases front caster negotiation while maintaining overall stability of the wheelchair/swingarm system.
- Because running a smaller drive wheel will reduce the vertical COG (Z axis) and wheel height. We recommend outfitting the wheelchair

with a hemi-kit for the elder testing. It will reduce the Z axis of the system by 1", increasing system stability while still enabling ease of front caster negotiation. It should also enable elders to have a longer period of contact with the drive wheels, increasing propulsion efficiency.

CHAPTER 7: DESIGN

Problem Solving: Ideation and Prototyping

Early in the design process, we identified problems pertaining to elders and wheelchair use. We also had a series of challenges to overcome based on the mechanisms we were designing. Sometimes problems were quite evident. At other times they revealed themselves during testing. However, throughout the evolution of this wheelchair concept, group brainstorming sessions, group and individual ideation, and prototyping kept the process moving forward. The following is the documentation of the process in sketch, photographic, and computer generated forms.

Design Criteria and Design Opportunities

As mentioned earlier in this report, based on analysis by the design team, design implications were identified pertaining to elders and wheelchair use from the R2b study and findings from the D2 Elder ADL Study and used to form design criteria. The following is a summary of the design development processes used to solve this complex problem set:

Design Criterion 1

The retail cost of the wheelchair will be at or under \$400. (This represents the highest amount that most NH administrators will pay for a wheelchair).

Design Opportunities: Material and Design Optimization

Design Criterion 2

The wheelchair will better accommodate individuals who propel with their hands, feet or a combination of both. (It was found in R2b that 34% of elders use their hands-only to propel, 18% used their feet only, and users that propelled using combinations of hand and foot motions represented 48% of this user population).

Implication1: *Moving the drive wheels closer to the COG eases propulsion in terms of reach, but decreases the stability of the user/wheelchair system.*

Design Opportunities: *Drive wheel location optimization and stabilizer development*

Solution: Derived through findings of the Literature Review, ADL study, Weight Distribution Study, and Obstacle Negotiation Study

Implication 2: *Wheelchairs with captive swingaway footrests stand to provide support for elders limbs when needed and prevent the frustration of wheelchair part loss.*

Design Opportunity: *Integrated Footrest Design*

Solution: Develop concepts for permanently mounted footrests to determine which will best meet the project needs. (see Figure 25 and ideation in Appendix).

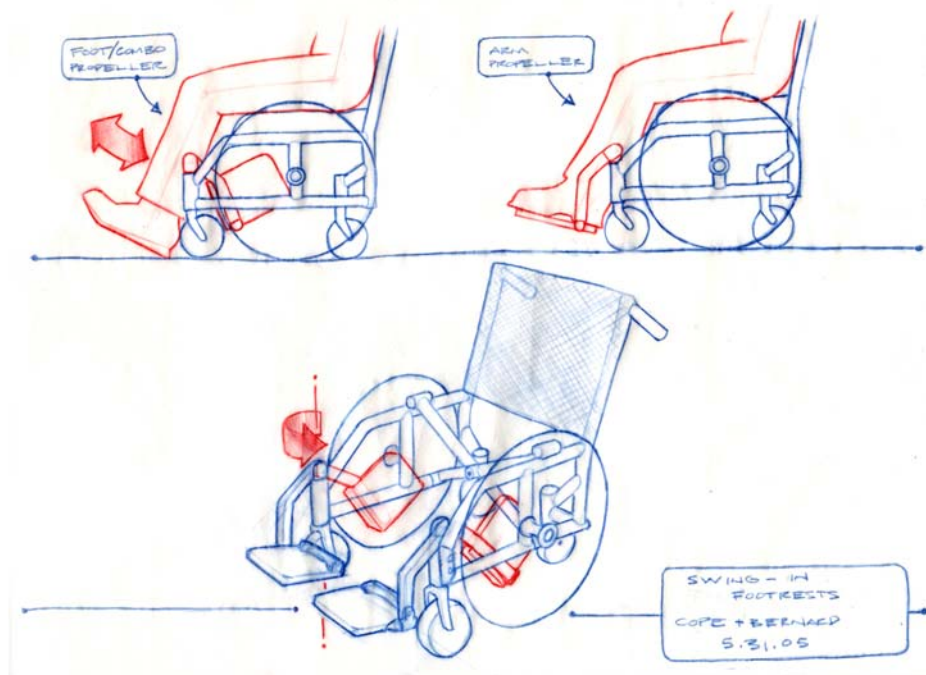


Fig 25. Permanently Mounted Swing-In Footrest

Implication 3: *It is difficult to find a good location for mounting standard wheel locks to a mid-drive type of configuration due to wheel placement*

Design Opportunities: *Reassess Wheel Locks*

Solution: Develop a new way to grab the drive wheel and lock it to accommodate the unique needs of elders and a wheelchair with swingarms (see Figure 26 and Appendix).

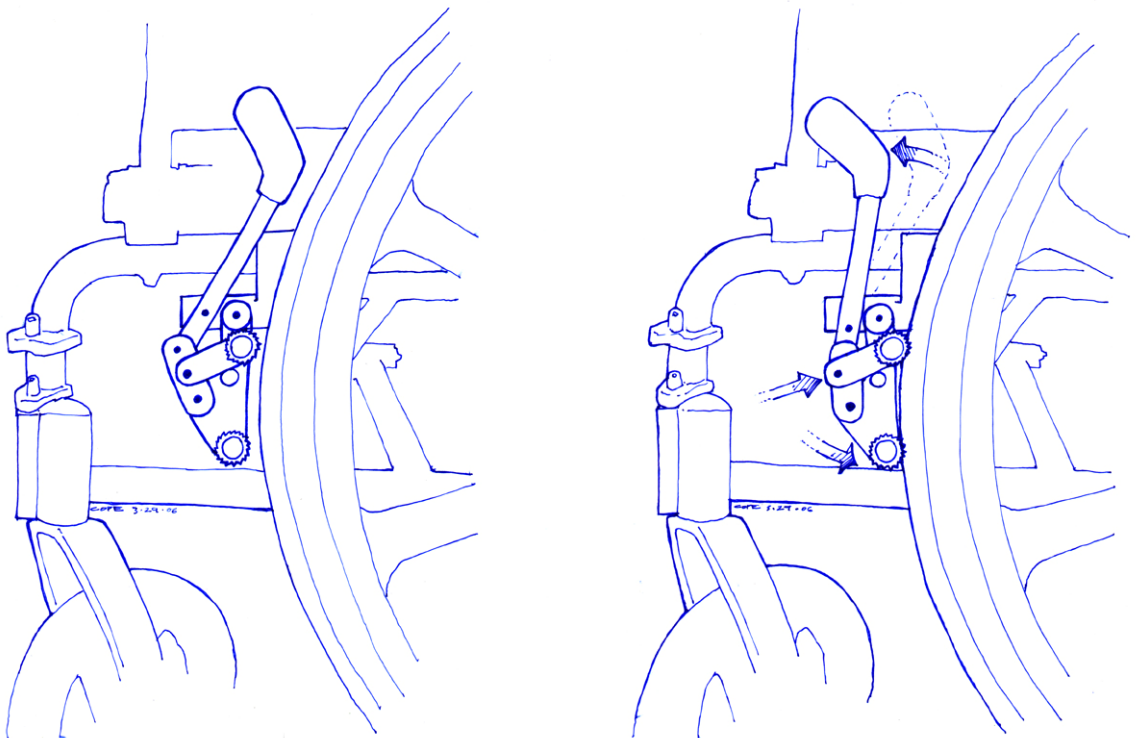


Fig 26. 2-Barrel wheel lock holds the wheel and the swingarm still by grabbing the wheel at 2 points.

Design Criterion 3

The wheelchair's human factors will be designed primarily for the user, but must also accommodate an attendant (pusher).

Implication 1: Problems with wheel bridging exist due to the use of front and rear casters on the mid-drive design. The drive wheels will lose contact with the ground when the front and rear casters encounter a sudden change in elevation (e.g. a ramp) -if they are rigidly mounted to the wheelchair.

Design Opportunities: Design dynamic methods of addressing wheel bridging

Implication 2: A wheelchair that can ease passage through narrow doorways, over obstacles, and easily transition from one surface to another will likely improve elder mobility and reduce injury.

Design Opportunities: Improving Maneuverability and Obstacle Negotiation

Solution (Design Criterion 3): Develop a variety of concepts to solve wheel-bridging problems to determine which will best meet the project

needs while still taking maneuverability into account (see Figure 27 and Appendix).

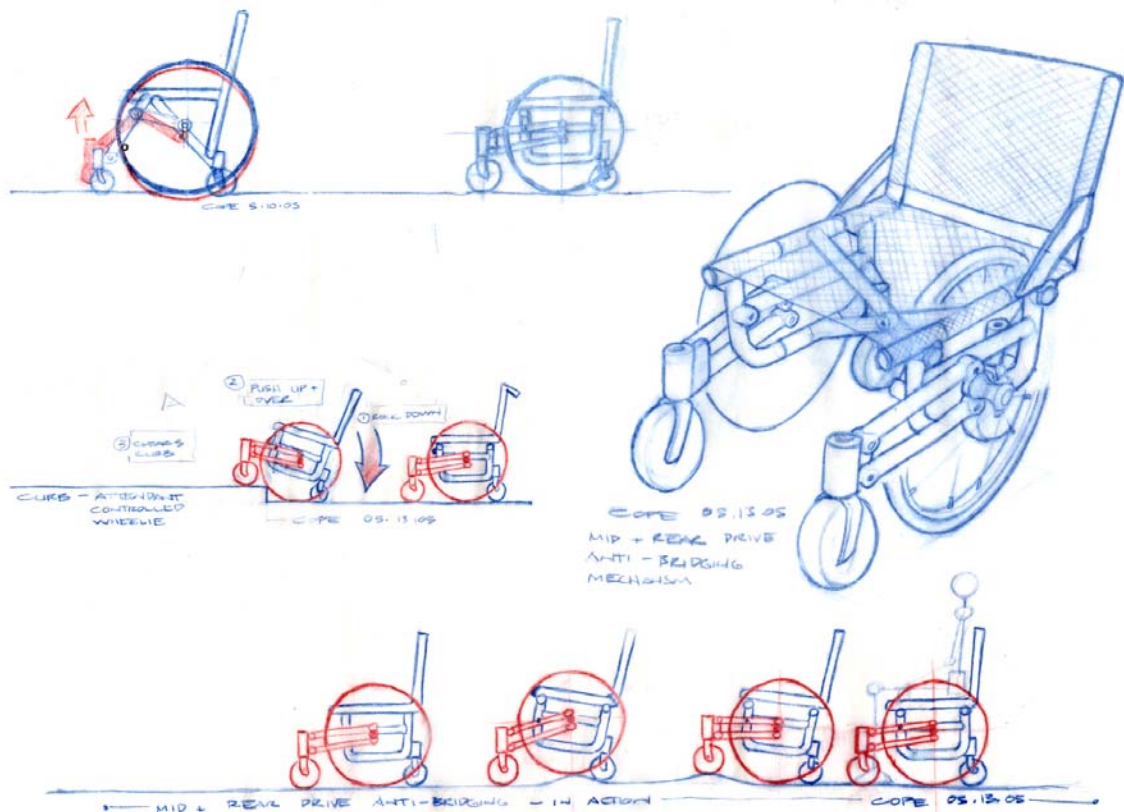


Fig 27. Bridging Mechanism (Swingarm)

Implications: Wheelchair features such as easy-to-use wheel locks, swingaway footrests, and transfer aids are crucial to elder safety when moving in and out of a wheelchair.

Design Opportunities: Design features that ease the ability of elders to move safely stand to reduce injuries that take place in NH's due to wheelchair use.

Solution: With a solid, viable wheel-lock solution already developed, attentions needed to be redirected to improve armrests from their current state.

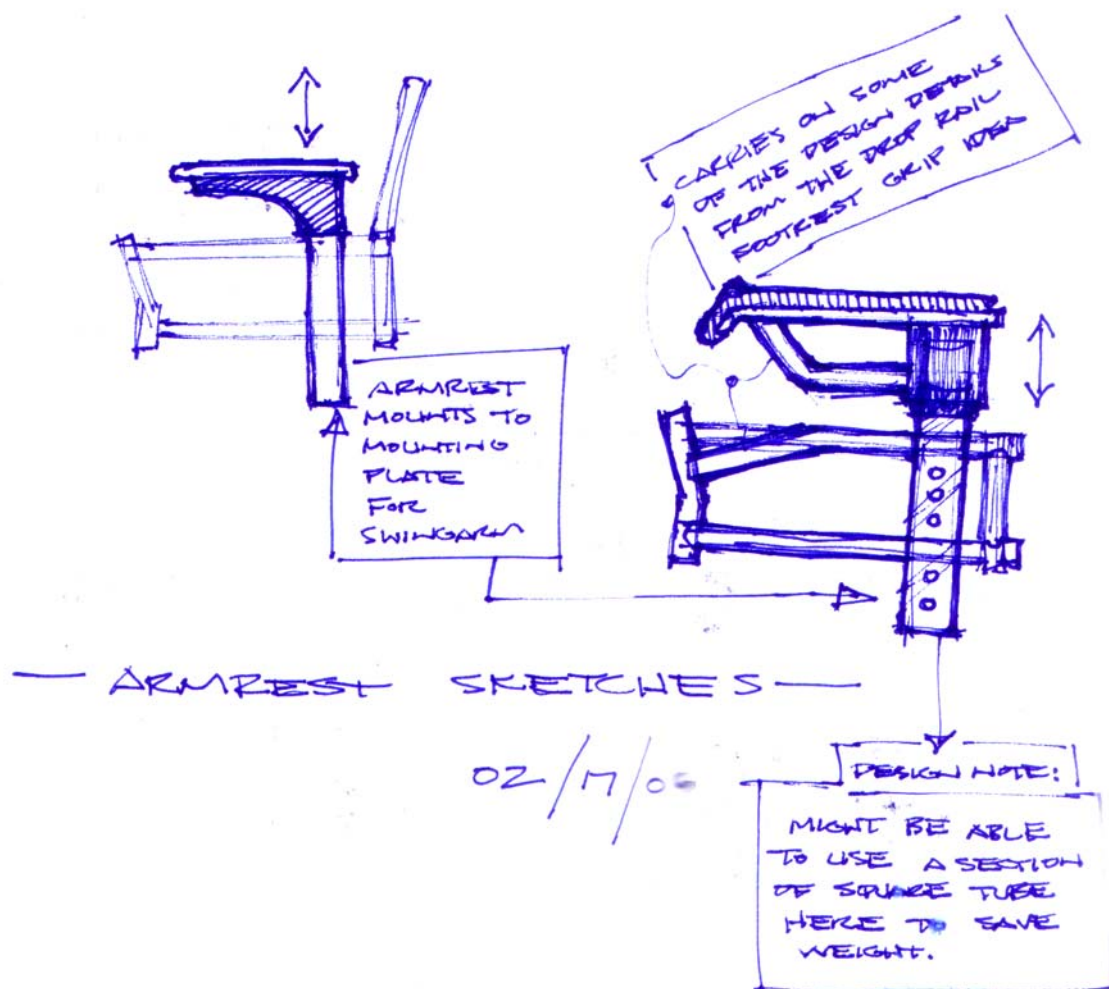


Fig 28. Sketches: Elder-Friendly Armrests (based on Sunrise Medical Zippie GS armrests)

Implication: *An attendant must still be able to easily push the wheelchair.*

Design Opportunities: *Drive wheel location optimization and stabilizer optimization:*

Solution: Test Mule 2 used casters that conflicted as minimally as possible with an individual's feet and ankles as they pushed the wheelchair while still minimizing the overall length of the wheelchair (see Figure 29).



Fig 29. Rear View – Test Mule 2 Rear Casters

Implication: *An easy-to-clean, low maintenance wheelchair that reduces care staff burden is essential to maintaining elder safety.*

Design Opportunity: *Simplicity of Form and Function*

Design Criterion 4:

The wheelchair will allow for folding.

Implication: *A wheelchair with the ability to fold makes it easier to store and transport, easing care staff duties and allows elders to have greater frequency of experiences outside a NH or ALF facility.*

Design Opportunity: *Reassessing Folding*

Solution: Research and sketch possible folding solutions to determine which will best meet the project needs (See Figure 30 and Appendix).



Fig 30. The Sunrise Medical Breezy Ultra 4 uses a simple camp-stool-type x-frame folding mechanism.

Design Criterion 5:

The front casters will be placed to reduce the interference with the users' feet and ankles during propulsion.

Implications: A wheelchair that eases combination and foot propulsion stands to aid in independent mobility. The legs and feet of elders need a

means of isolation from contact with casters during propulsion to reduce injury.

Design Opportunities: *Running smaller casters or casters with less trail reduces the risk of caster contact with elders' legs and feet.*

Solution: Use 6" casters and caster forks with 2" of trail instead of 3-4" of trail. This increases foot and ankle clearance by over 3" (see Figure 31).



Fig 31. Depot Wheelchair (7" Ankle Clearance)



Test Mule 2 (10" Ankle Clearance)

Design Criterion 6:

The overall length of the wheelchair will be less than 38".to improve maneuvering in tight spaces. This criteria is based on review of typical K001 wheelchairs and finding difficulty in passing ANSI/RESNA Standard tests for turning radius and turns in place.

***Design Opportunities:** Frame optimization, drive wheel location optimization, and stabilizer optimization*

Design Criterion 7:

Maintain a maximum base of support (wheelbase) for the wheelchair to be at or less than 19 inches. (Nineteen inches is the typical length for the base of support found on most K0001 wheelchairs.)

***Design Opportunities:** Drive wheel location optimization and stabilizer optimization*

Solution: Create a swingarm system that does not add additional length to the wheelchair.

Design Criterion 8:

The wheel track (width) of the wheelchair will be comparable to a current K0001 chair (21.5 " - 21.75").

***Design Opportunities:** Drive wheel location optimization and stabilizer optimization*

Solution: Create a swingarm system that does not add additional girth to the wheelchair.

Design Criterion 9:

The weight of the wheelchair will be between 29 and 34 lbs (making it the same weight or lighter than most K0001 chairs).

Design Opportunity: Material Optimization

Solution: Create a frame that minimizes weight while still being low maintenance and durable.

Design Criterion 10:

The wheelchair will be equal to the static stability of a current K0001 chair.

Design Opportunity: Swingarm Optimization

Solution: Understand how the swingarm system works so that it can be explained to the corporate partner as they subject the wheelchair concept to this testing.

“Nice to Have . . .” Ideas and Design Opportunities

The “Nice to Have” designs we developed are unfortunately cost prohibitive at this time. Sketches and ideation of these ideas can be found in the Appendix.

Test Mule A Testing and Design Opportunities

The number of possible swingarm configurations were seemingly infinite. We needed to create an easily reconfigurable means to simulate a wide variety of swingarms for performance testing. We also needed to create a means to weigh a 6 wheeled wheelchair’s front casters, drive wheels, and rear casters as individual elements of the system aid in system optimization. (See Fig 10-12).

Test Mule B Testing and Design Opportunities

In order to further optimize the elder wheelchair, we created 2 prototype frames to give it weight characteristics that would be more similar to a K0001 or our K0003 test chair (A Sunrise Medical Breezy). Figure 32 features one of the swingarms and frames that we created to lighten the test mule.



Fig 32. Drive wheel removed to show lightweight frame and swingarm of test mule 2

Test Mule B Optimization and Design Opportunities

Based on the results of the AB Pilot Study, we further optimized the elder wheelchair. I created 3 new prototype swingarms with improved forward and reverse obstacle negotiation abilities. The following represents the solutions that we created.

CAD Development

Based on design criteria, system optimization, and knowledge gained over the evolution of the elder wheelchair project, we designed a production frame concept and built a 3-D model in SolidWorks. It was developed using parts from Sunrise Medical's existing parts listing as well as new and unique design elements like swingarms and captive footrests. Figures 33 to 39 show three-quarter, side, top, front, and back views of the final wheelchair. Sunrise Medical will use this CAD data to develop a prototype mid-drive wheelchair for in-house testing and further testing at CATEA -on the road to a production model wheelchair.

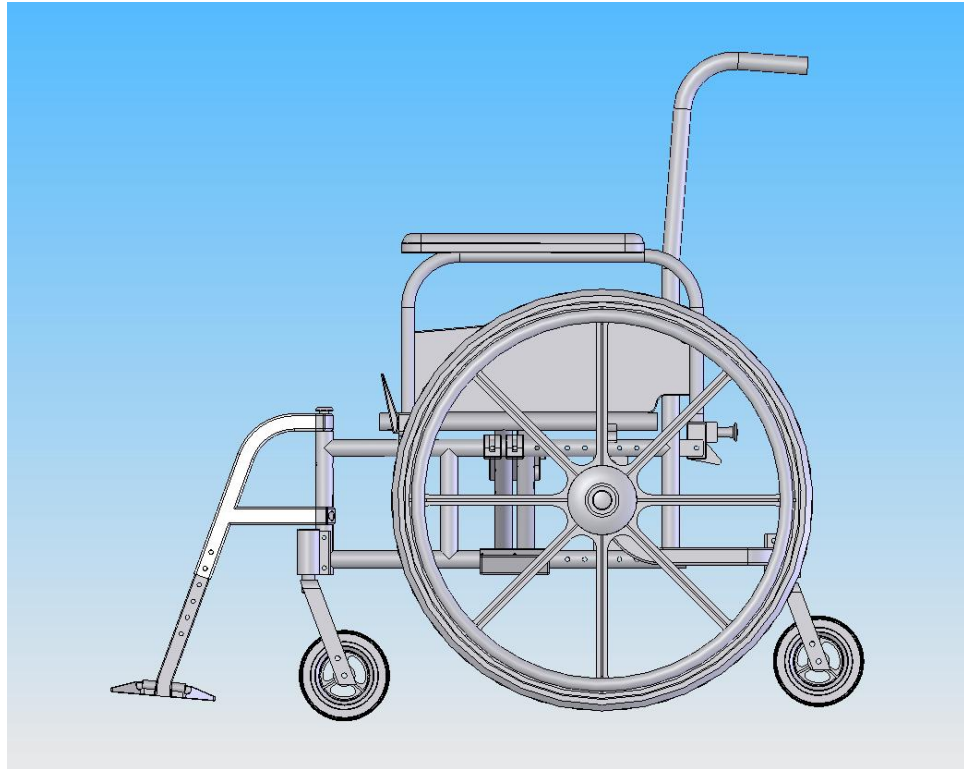


Fig 33. SolidWorks Model (Right Side)

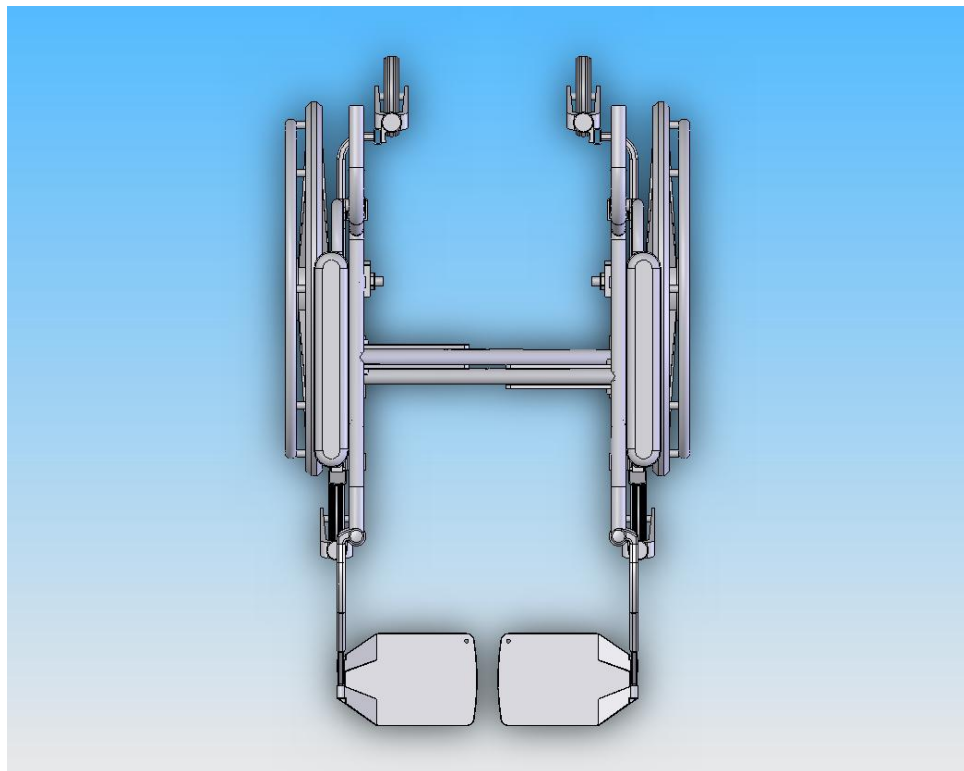


Fig 34. SolidWorks Model (Top View)

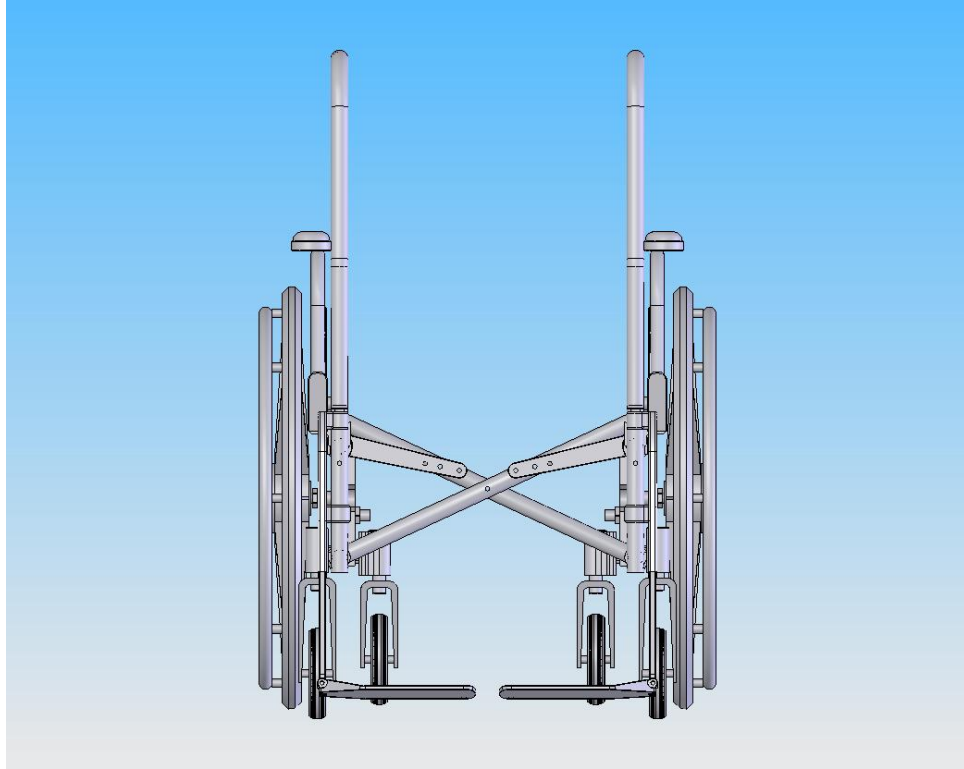


Fig 35. SolidWorks Model (Front View)

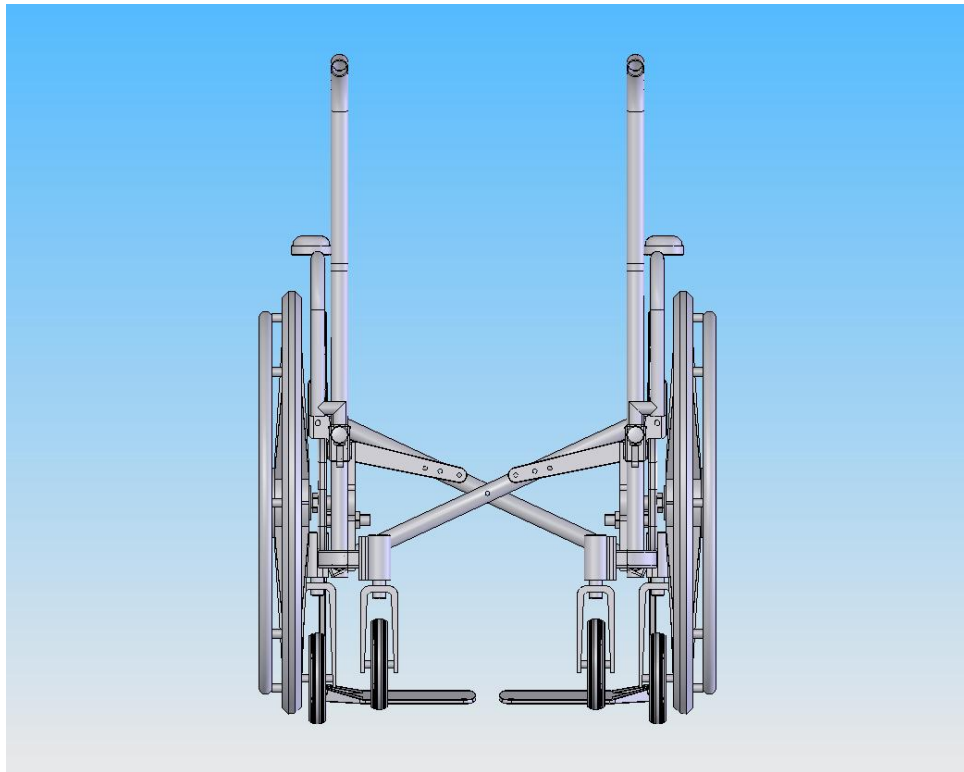


Fig 36. SolidWorks Model (Back View)



Fig 37. SolidWorks Model (3/4 View-Front)

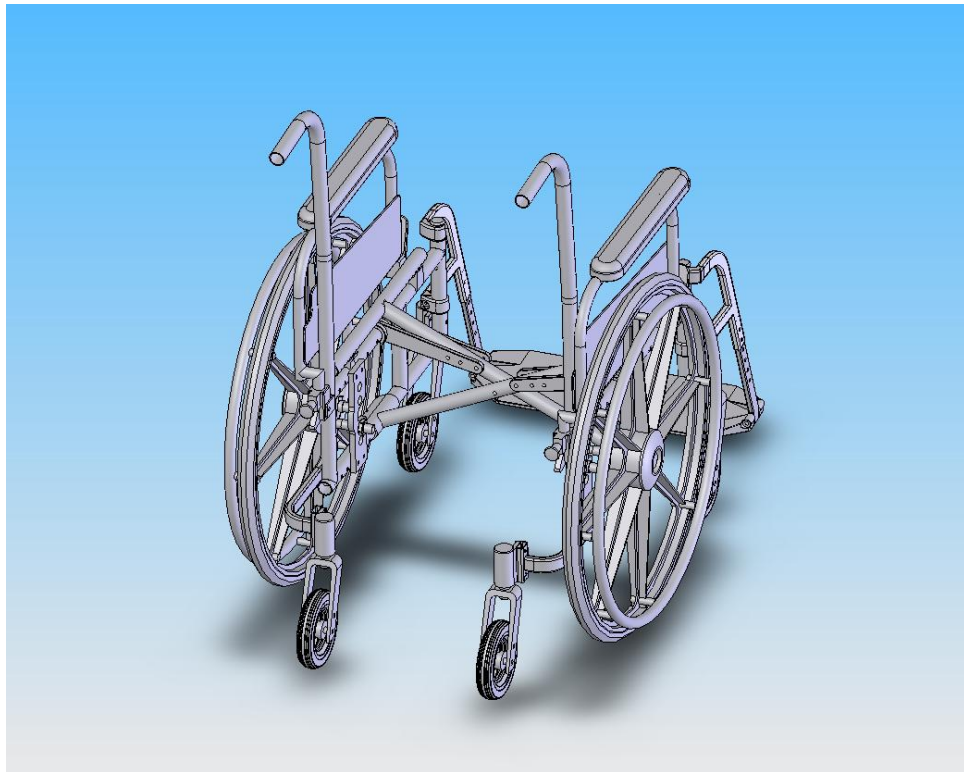


Fig 38. SolidWorks Model (3/4 View – Rear)

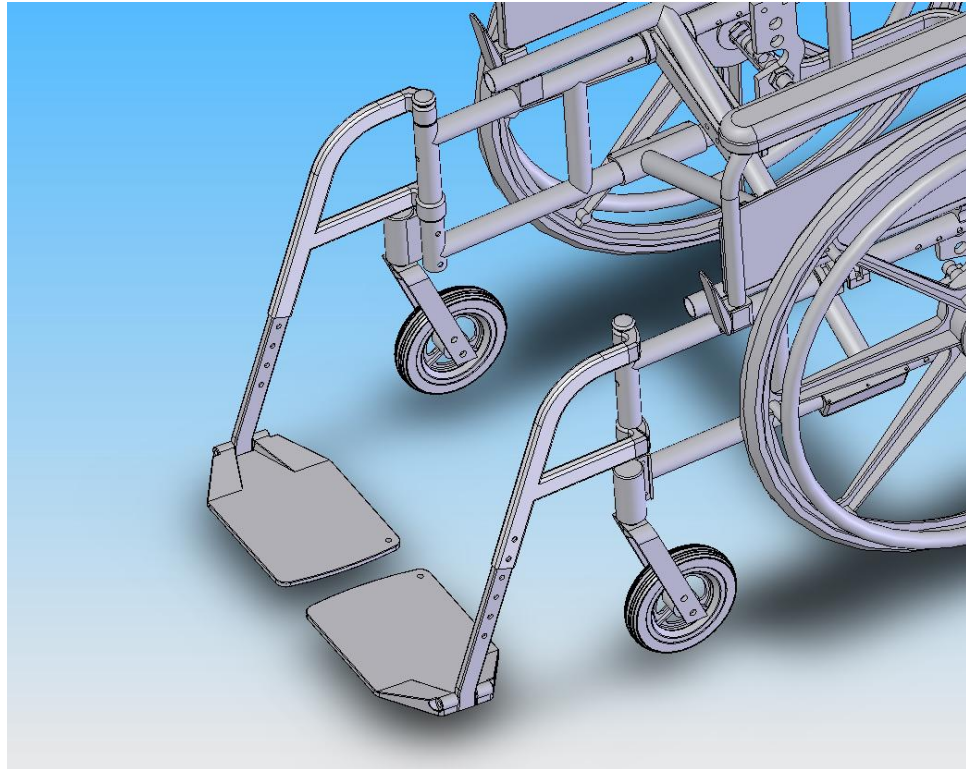


Fig 39. SolidWorks Model (Detail –Fold-In Captive Footrests)

Final Ergonomic Improvements and Assessments

There are several areas of this wheelchair that have been identified as areas that can be improved to enhance the experience of both the primary user and their caregivers. Through improving the tactile experience of controls and looking at secondary stakeholders, we can more completely address the intuitiveness and safety of this wheelchair for not only elders, but their caregivers as well.

'Tactification' and Ergonomics

The front edge of the armrests, latching systems (armrests & footrests), and wheel locks all can stand to be improved through 'tactification' or making these surfaces more tactile. They need to intuitively say "touch me" to the user. Whether our cognitive abilities go into decline (via age or other conditions) or if we see many different wheelchairs each day (like a caregiver or nursing home employee) making the surfaces that our fingers come into contact with as easy to manipulate as possible and good to touch is key. Making products' control surfaces pleasurable and easy to use, especially a product like a wheelchair with many different controls and releases, creates a net effect of usability. If the controls are placed properly and give the user tactile feedback you've not only created a product that 'works right', but 'feels right' as well.

During the next product development stage with our corporate partner, we will be strongly recommending the addition of textured Santoprene or polyurethane grip areas to footrest controls, armrest controls, wheel lock grips, handgrips, and leading edges of armrests.

User Safety and Ergonomics

User safety must also be heightened in the footrest and hand grip zones.

To improve the safety of wheelchair users, we will be integrating high-traction footrest surfaces in addition to straps that are flexible yet not easily compressible by the users heels. These will help to keep feet easily and securely on the footrest surfaces when/if the footrests are in use.

To improve the safety of caregivers and nursing home employees, the design of a foldable or detachable pushbar that distances them from the rear casters of the wheelchair may become important. The rear casters are closer to each other than the main drive wheels of the wheelchair and could conceivably interfere with the feet of attendants as they push the wheelchair. Their safety is just as key as the safety of the elders that use this wheelchair. Happy caregivers lead to happier NH and ALF residents.

CHAPTER 8: PROJECTIONS AND CONCLUSIONS

Design Goals Met: Elder Wheelchair Development Project (D2)

- 1) *The retail cost of the wheelchair is approximately \$400.*
- 2) The wheelchair better accommodates individuals who propel with their hands, feet or a combination of both *via a swingarm stabilizer system that allows drive wheel placement that is closer to the user-wheelchair system COG.*
- 3) The wheelchair's human factors are designed primarily for the user, but also accommodate an attendant (pusher) *via its innovative swingarm stabilizer design.*
- 4) The wheelchair allows for folding *using a simple camp stool folding design.*
- 5) The front casters are placed to reduce the interference with the users' feet and ankles during propulsion *via 6" casters and forks with 2 ¼" of trail.*

6) The overall length of the wheelchair is less than 38".to improve maneuvering in tight spaces. This criteria is based on review of typical K001 wheelchairs and finding difficulty in passing ANSI/RESNA Standard tests for turning radius and turns in place. ***Our chair falls at 30 ¼" inches - well under that of wheelchairs that prove problematic for this task. It is equal in length to an Invacare Tracer EX2, a commonly prescribed K0001 Wheelchair.***

7) Maintain a maximum base of support (wheelbase) for the wheelchair to be at or less than 19 inches. Nineteen inches is the typical length for the base of support found on most K0001 wheelchairs. ***Our chair falls at 14.75" from the front casters to the drive wheels and 12.25" from the drive wheels to the rear casters.***

8) ***The wheel track (width) of the wheelchair is comparable to a current K0001 chair at 21.5".***

9) The weight of the wheelchair is ***projected at 30 lbs*** (making it the same weight or lighter than most K0001 chairs).

10) The wheelchair will be equal to the static stability of a current K0001 chair. ***(This testing will be performed by our corporate partner).***

11) Items that the user needs to operate have been accentuated or improved to ease use *via improved armrests for ingress and egress and elder-friendly wheel locks.*

12) Due to its features, the wheelchair will be listed under the K0003 code - yet the cost will fall under the K0001 reimbursement rate. *Our projected \$400 price tag makes this a promising possibility. Smart marketing could make this goal a reality.*

Projections

If Sunrise Medical can produce this wheelchair in ample volume, this wheelchair design will easily fall within the \$400.00 price point stated in the design criteria. It may be possible to offer this wheelchair through other channels than wheelchair dealers to further penetrate the ever-growing elder wheelchair market. Online retailers exist that now sell wheelchairs direct to the public. Sears, a name well-known to baby-boomers has even gotten into the act with their "Health and Wellness" catalog (see Figure 40).

How to Adjust Your Footrest

Measure the user from the bottom of the heel to the under-surface of the thigh at the back of the knee. Add 1" to the above measurement. If a seat cushion is to be used, subtract one-half the thickness of the cushion from the total. The footrest cannot extend beyond a level 2" above the surface of the floor.

Lightweight Folding Aluminum Transport Chair with Mag Style Wheels

Ultra-lightweight compact folding wheelchair is ideal for personal transportation anywhere. Constructed of aluminum tubing and 8" composite mag style front wheels and 12" solid rear wheels. This wheelchair features padded full arm rests for comfort, hand brakes, and dual wheel lock for security. Also includes swing away footrest with adjustable foot straps. Seat height: 18 1/2", seat width: 19", back height: 19". Capacity: 250 lbs. Chair weighs less than 19 lbs. and foot rests 3 1/2 lbs. Comes in Royal Blue.

2398 \$259.99

Lightweight Wheelchair Rolls Easily with Less Effort

At 32 lbs., this chair is ideal for those on the go. Nylon seat and padded back. Seat to floor measures 19 1/2". Backrest adjusts from 15"-19". Capacity 300 lbs. Folds up easily for storage. Warranted.*

1820 Seat 16"W x 16"D Flip Back Desk Arms	\$499.99
1821 Seat 18"W x 16"D Flip Back Desk Arms	\$499.99
1822 Swing Away Footrest	\$49.99

Aluminum Transport Wheelchair

Only Weighs 19 lbs.

Lightweight aluminum frame is strong and durable. 19" seat includes a seat belt for added safety. Folds down for easy storage and transport. Comes with swing-away footrests. Supports up to 300 lbs. 22"x38" overall. Choose Silver, Blue or Green. Warranted.*

1745 \$219.99

Combination Transport/Wheelchair

Unique design allows chair to be converted from a transport chair to a wheelchair. Quick-release 24" wheels can be removed for ease of use by a caregiver or for transporting the chair. Features folding arms and back, 8" casters, dual brakes for use in either mode, nylon upholstery and a pocket in back. Seat: 18"x16", 9 1/2" from floor. Width: 24 1/2". Weighs: 29 lbs. Capacity 250 lbs.

4344 \$499.99

Chrome Transport Chair

Lightweight and maintenance free, features durable nylon upholstery, padded armrests and composite wheels. Handles fold for easy storage. Swing-away footrests of durable die cast aluminum. Less than 26 lbs. without foot rest. Seat is 19" wide. Capacity 300 lbs. 22"x38" Limited Lifetime Warranty*

41000 \$159.99

new item!

1.800.326.1750

*Warranted, see ordering information.
†On Sears Card, see ordering information.
▲Special Return Policy, see ordering information.

Fig 40. Sears Health and Wellness Catalog – Wheelchair Section

The use of 1" OD aluminum tubing with a 0.065" wall, a standardly specified size in the wheelchair industry, no radical bends, and minimal welds, will make for a strong, light, and affordable frame. The use of a standard camp stool folding mechanism, seat, drive wheels, and axle mounts found on the Breezy and casters and armrests from the Quickie line can be pulled from Sunrise's existing parts toolbox –requiring no further tooling for these components. The swingarms will be constructed from easily acquired 1" x 0.5" cro-moly steel rectangular tubing with a 0.065" wall, making for durable swingarms that can take a lifetime of abuse. The swingarm mounts will be constructed from flat 0.375" thickness aluminum plates that require only simple cutting and boring operations and the insertion of 3 Sunrise Breezy axle mounts to be constructed. All components will be powercoated for a low-cost yet durable finish.

If this wheelchair can penetrate the wheelchair market, it stands to improve the mobility of elders. They will finally be using a wheelchair that is designed better accommodate their population's unique primary means and methods of propulsion (like combination and foot propulsion). They will be using a wheelchair that is not only better for their functional needs, but safer for them as well. Nursing homes and individual users alike stand to benefit from the use of this product.

Maximizing range of motion and conversation are 2 key auxiliary benefits of this wheelchair exist for users due to the use of swingarms. The swingarms enable the drive wheels to be placed directly under the user's shoulders. This position places the arms in a position where they can provide maximum power to the drive wheels while requiring minimal flexion of the shoulder joint. Caregivers can tilt elders back in the chair to provide a recline function while in the chair. This may provide a form of pressure relief and a nice position for watching 'Guiding Light' but also provides a better line of sight for conversation for the many kyphotic wheelchair users found in the NH environment. Staying active is key to maintaining elder health and autonomy –this wheelchair supports that though supporting mobility and socialization.

If the results of the elder cohort study prove promising, this wheelchair could show benefits to not only the elder population, but also those with spinal cord injury, multiple sclerosis, or other users with mobility needs that require a wheelchair. The swingarm mechanism can be adjusted to fit the needs of the most active to the least active of user.

Conclusions

The elder wheelchair concept stands to significantly benefit the elder population. As elders lose mobility with age, due to chronic disease, injury, or cognitive impairments, the ability to perform activities of daily living declines. A wheelchair that can improve the ability of this ever-growing portion of the population to perform ADLs would be a boon to keep elders independent longer and vastly improve quality of life.

APPENDIX A SKETCHING AND RESEARCH

Design Criteria Problem Solving

Design Criterion 2

The wheelchair will better accommodate individuals who propel with their hands, feet or a combination of both. (It was found in R2b that 34% of elders use their hands-only to propel, 18% used their feet only, and users that propelled using combinations of hand and foot motions represented 48% of this user population).

***Implication 2:** Wheelchairs with captive swingaway footrests stand to provide support for elders limbs when needed and prevent the frustration of wheelchair part loss.*

***Design Opportunity:** Integrated Footrest Design*

Solution: Develop concepts for permanently mounted footrests to determine which will best meet the project needs. (see Figure 25 and ideation in Appendix).

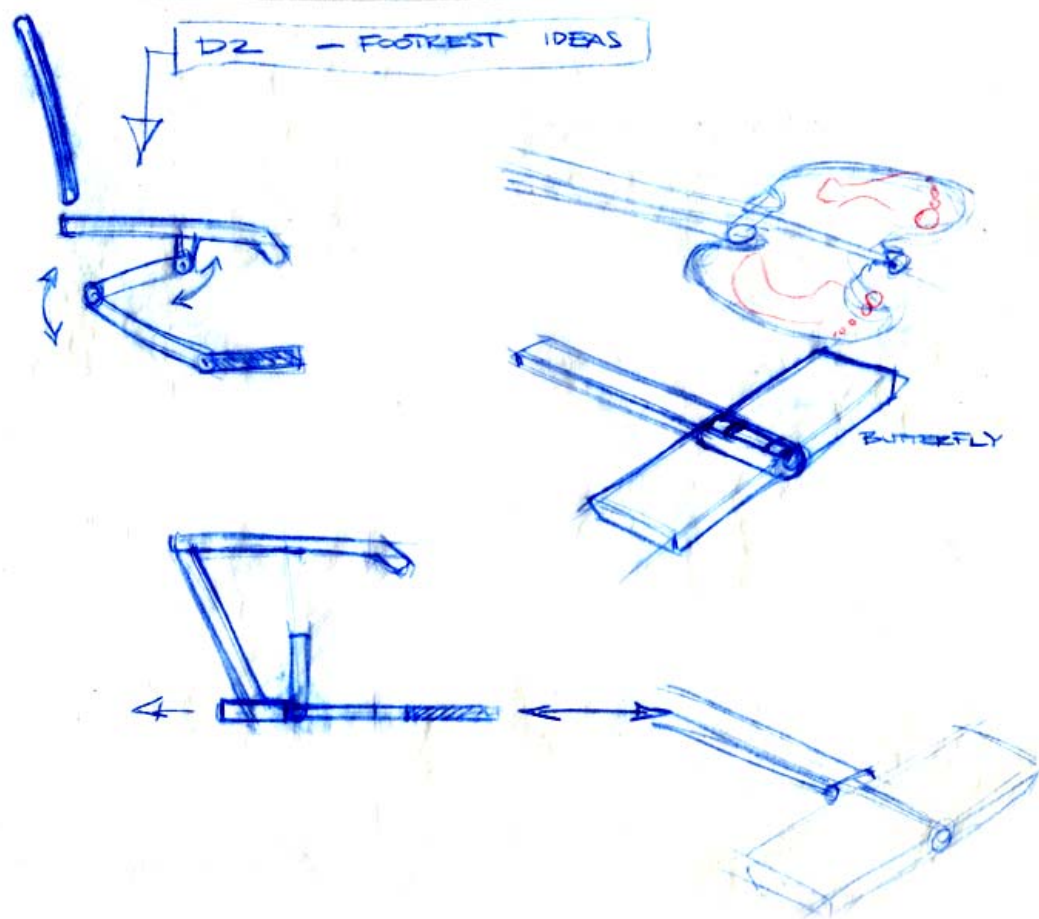


Fig 41. Fold-Under and Butterfly Footrest Concepts

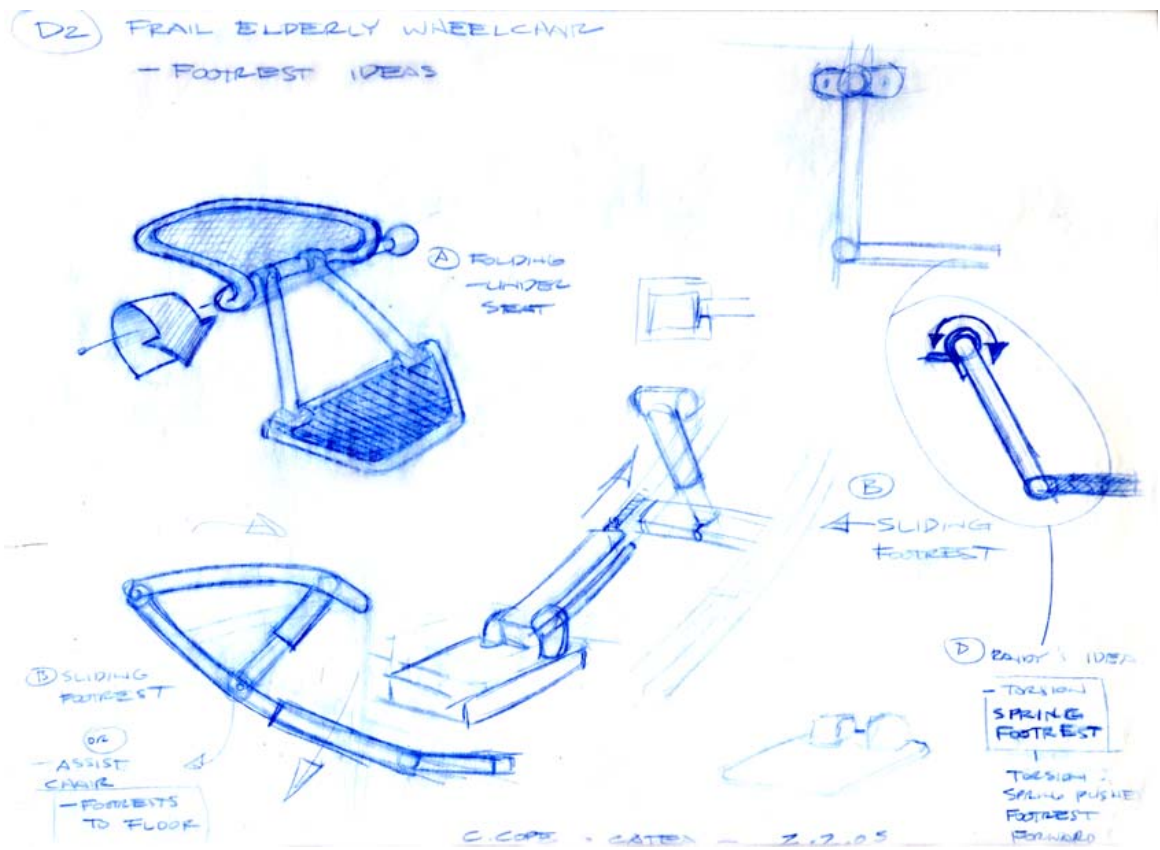


Fig 42. Swing-Under and Slide-Under Footrest Concepts

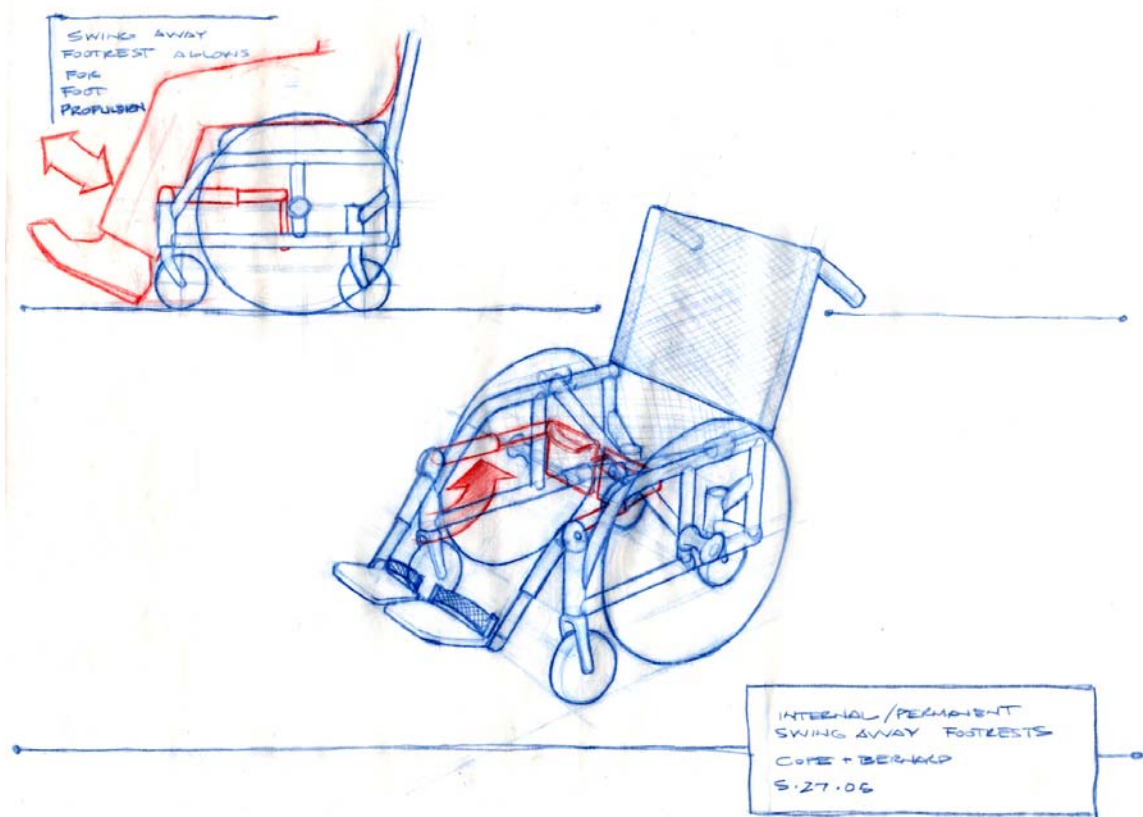


Fig 43. Swing-Up Footrest

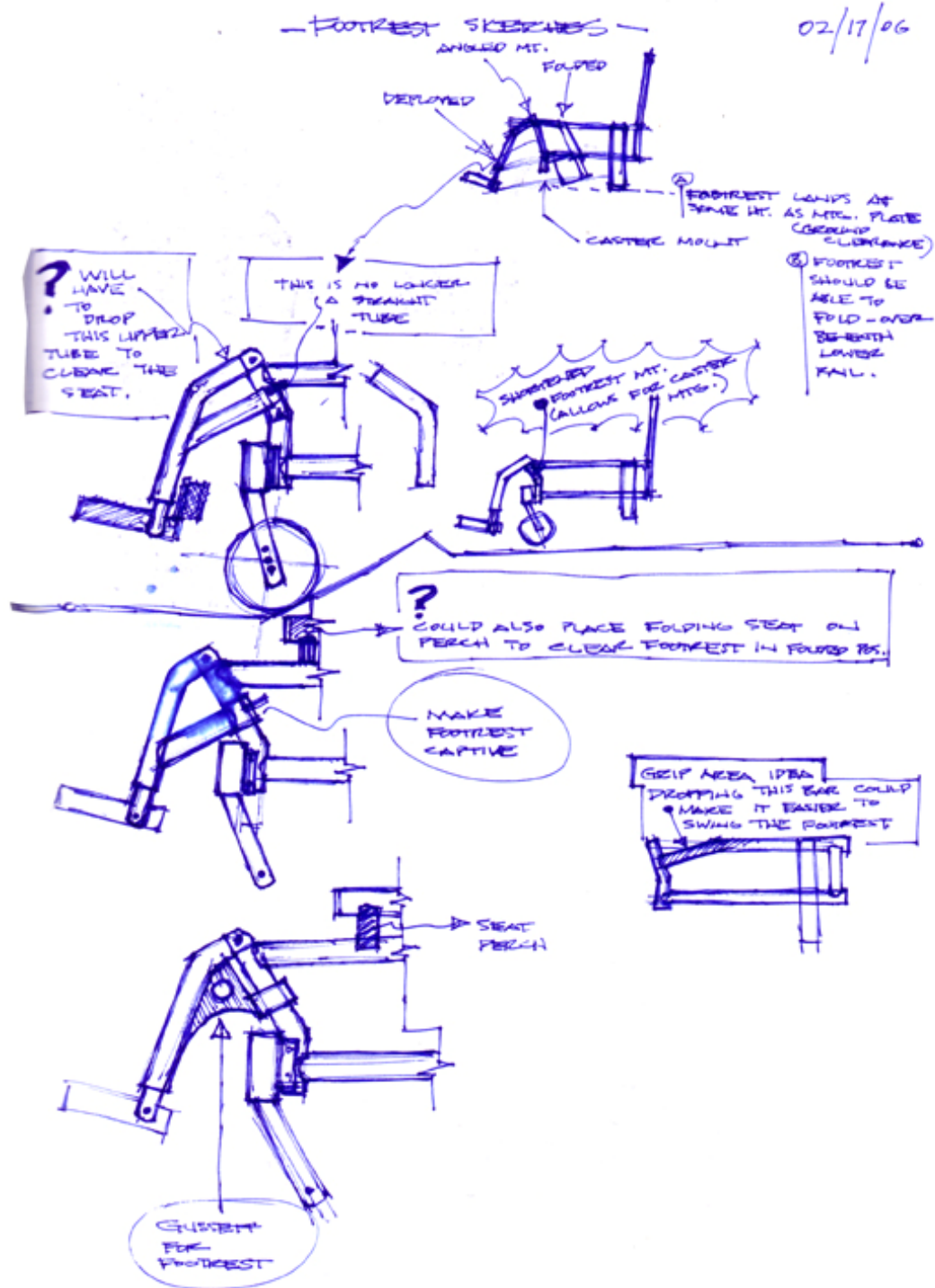


Fig 44. Swing-In Footrest – Refinement

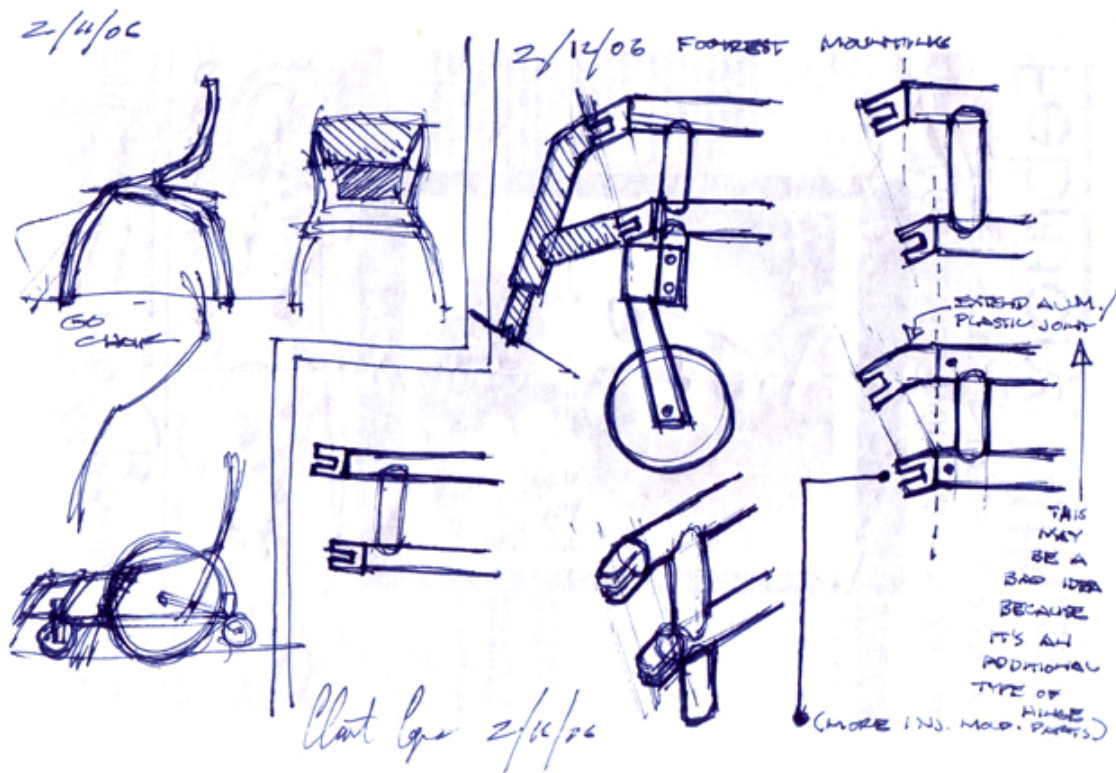


Fig 45. Swing-In Footrest – Further Development

Design Criterion 3

The wheelchair's human factors will be designed primarily for the user, but must also accommodate an attendant (pusher).

Implication 1: Problems with wheel bridging exist due to the use of front and rear casters on the mid-drive design. The drive wheels will lose contact with the ground when the front and rear casters encounter a sudden change in elevation (e.g. a ramp) -if they are rigidly mounted to the wheelchair.

Design Opportunities: Design dynamic methods of addressing wheel bridging

Implication 2: A wheelchair that can ease passage through narrow doorways, over obstacles, and easily transition from one surface to another will likely improve elder mobility and reduce injury.

Design Opportunities: Improving Maneuverability and Obstacle Negotiation

Solution (Design Criterion 3): Develop a variety of concepts to solve wheel-bridging problems to determine which will best meet the project needs while still taking maneuverability into account (see Figures 46 – 51 and Figure 27).

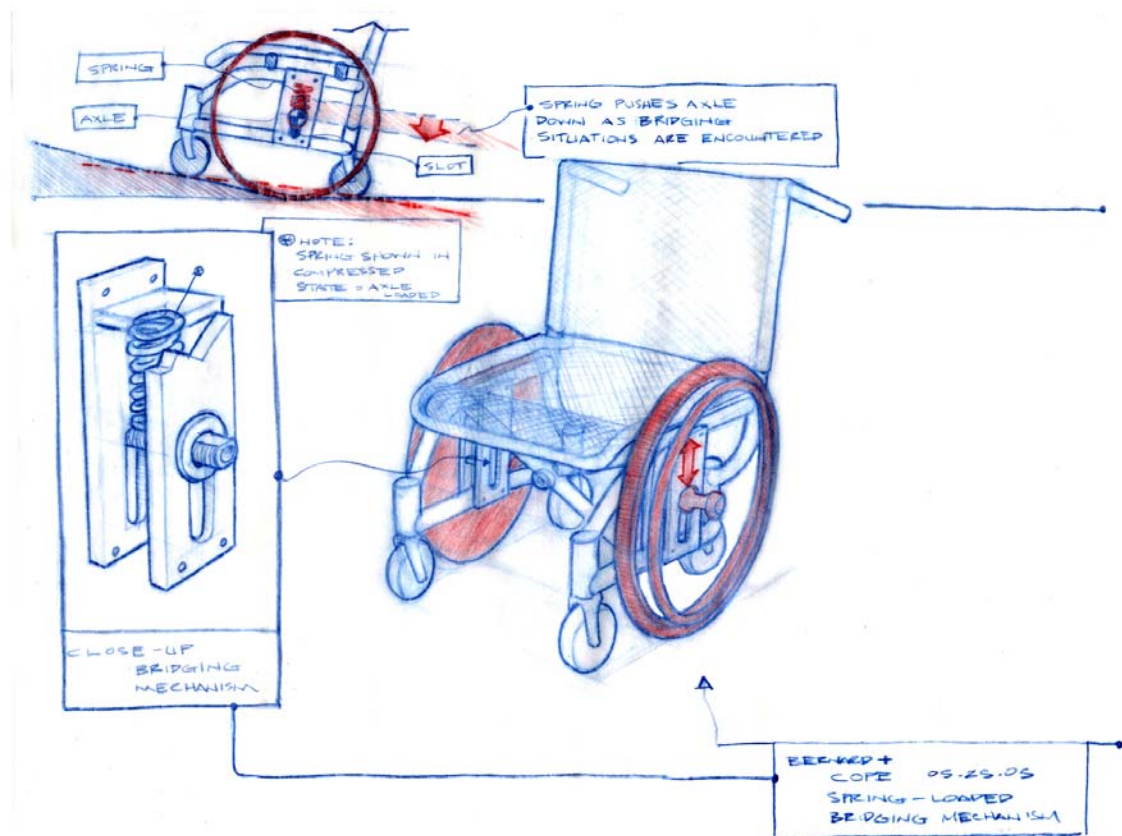


Fig 46. Bridging Mechanism (Coil Spring)

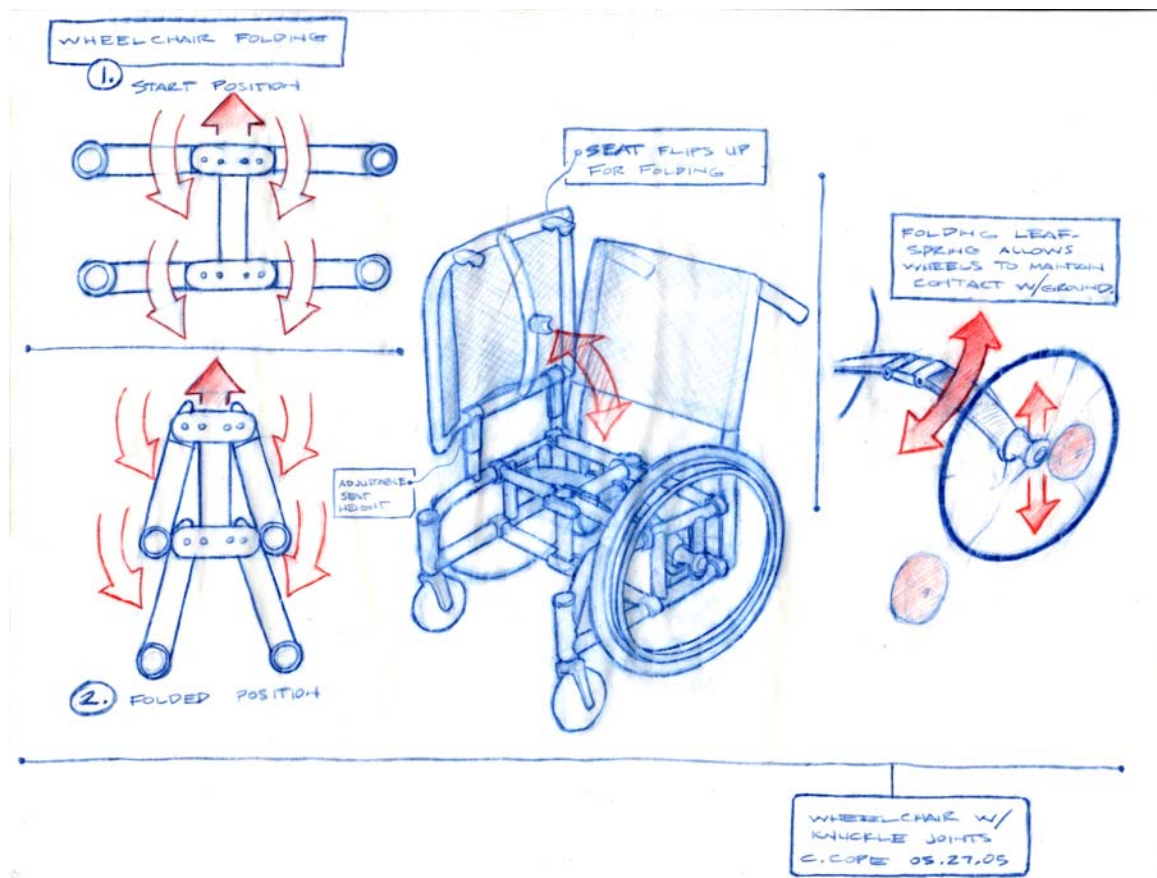


Fig 47. Bridging Mechanism (Leaf Spring)

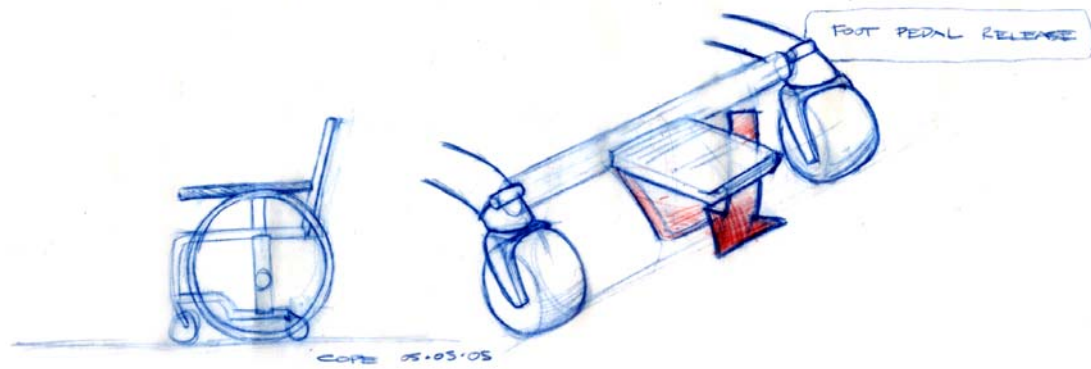


Fig 48. Attendant Operated Tilt Mechanism A (Actuation Concept B)

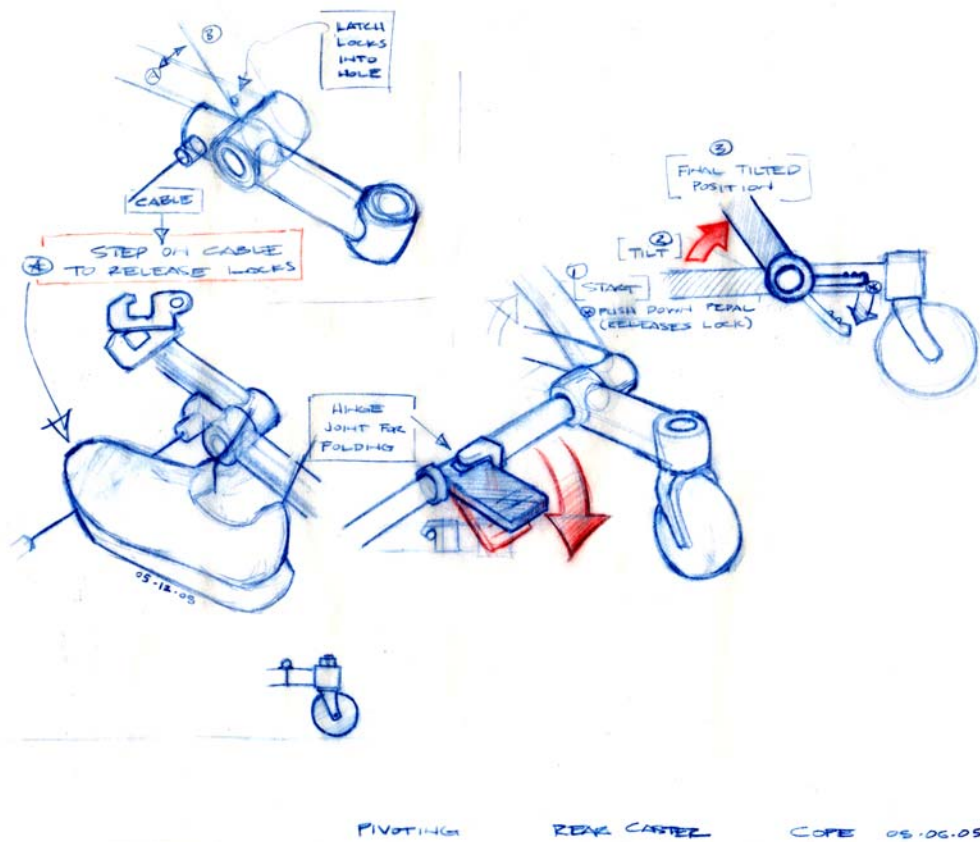


Fig 49. Attendant Operated Tilt Mechanism A (Actuation Concept A)

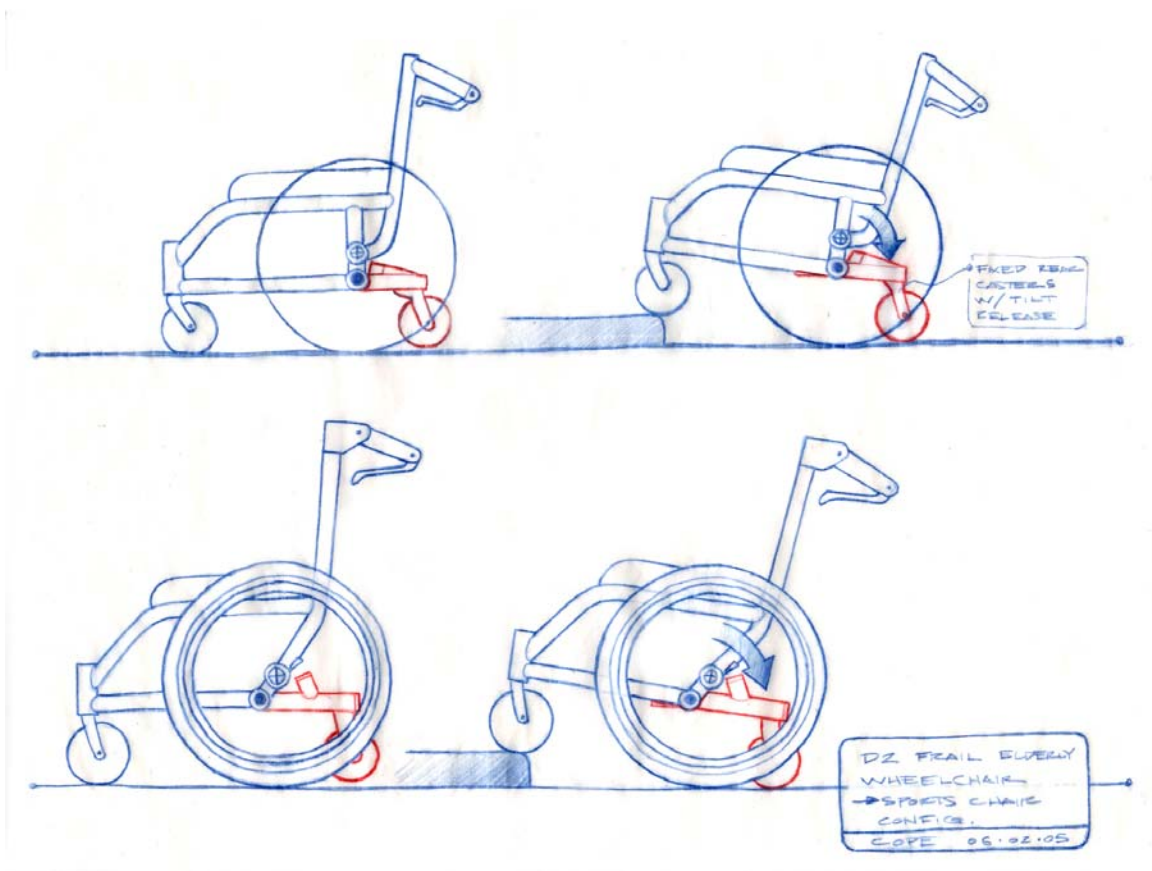


Fig 50. Attendant Operated Tilt Mechanism B

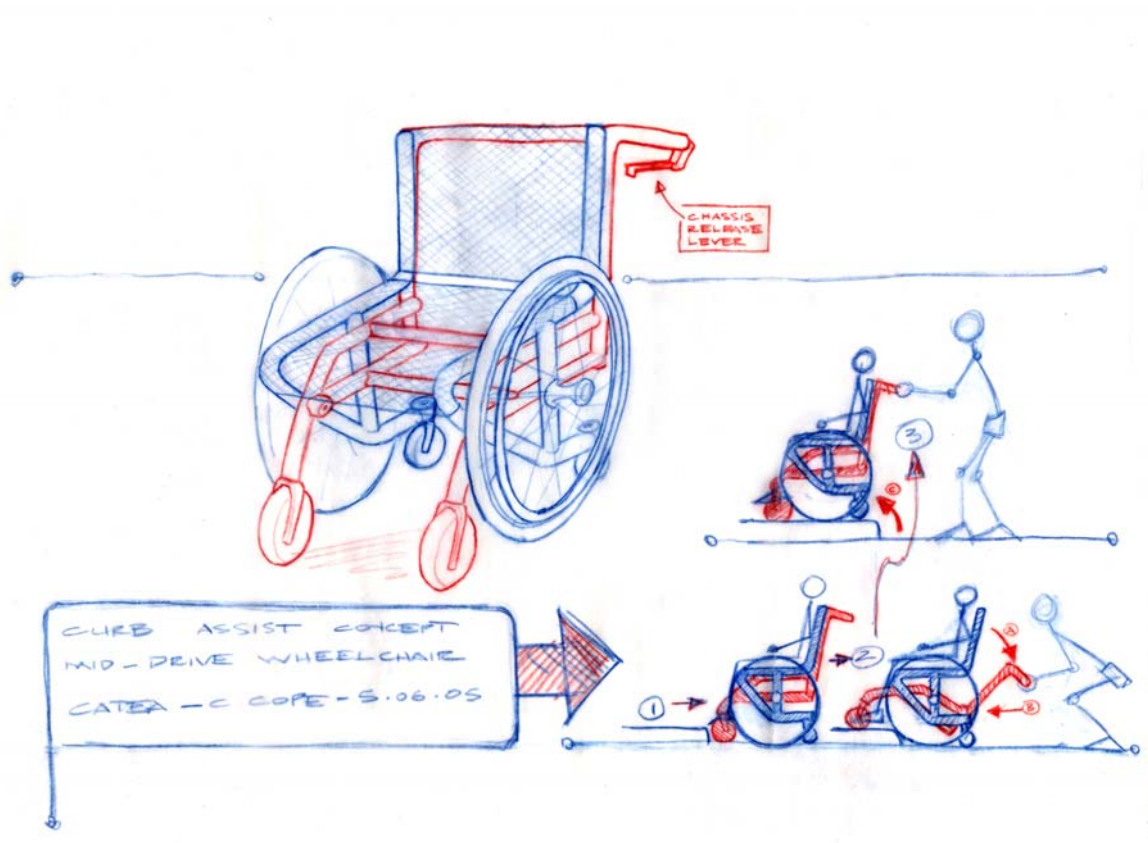


Fig 51. Attendant Operated Tilt Mechanism A

Implication 3: It is difficult to find a good location for mounting standard wheel locks to a mid-drive type of configuration due to wheel placement

Design Opportunities: Reassess Wheel Locks

Solution: Develop a new way to grab the drive wheel and lock it to accommodate the unique needs of elders and a wheelchair with swingarms (see Figures 26 and 52).

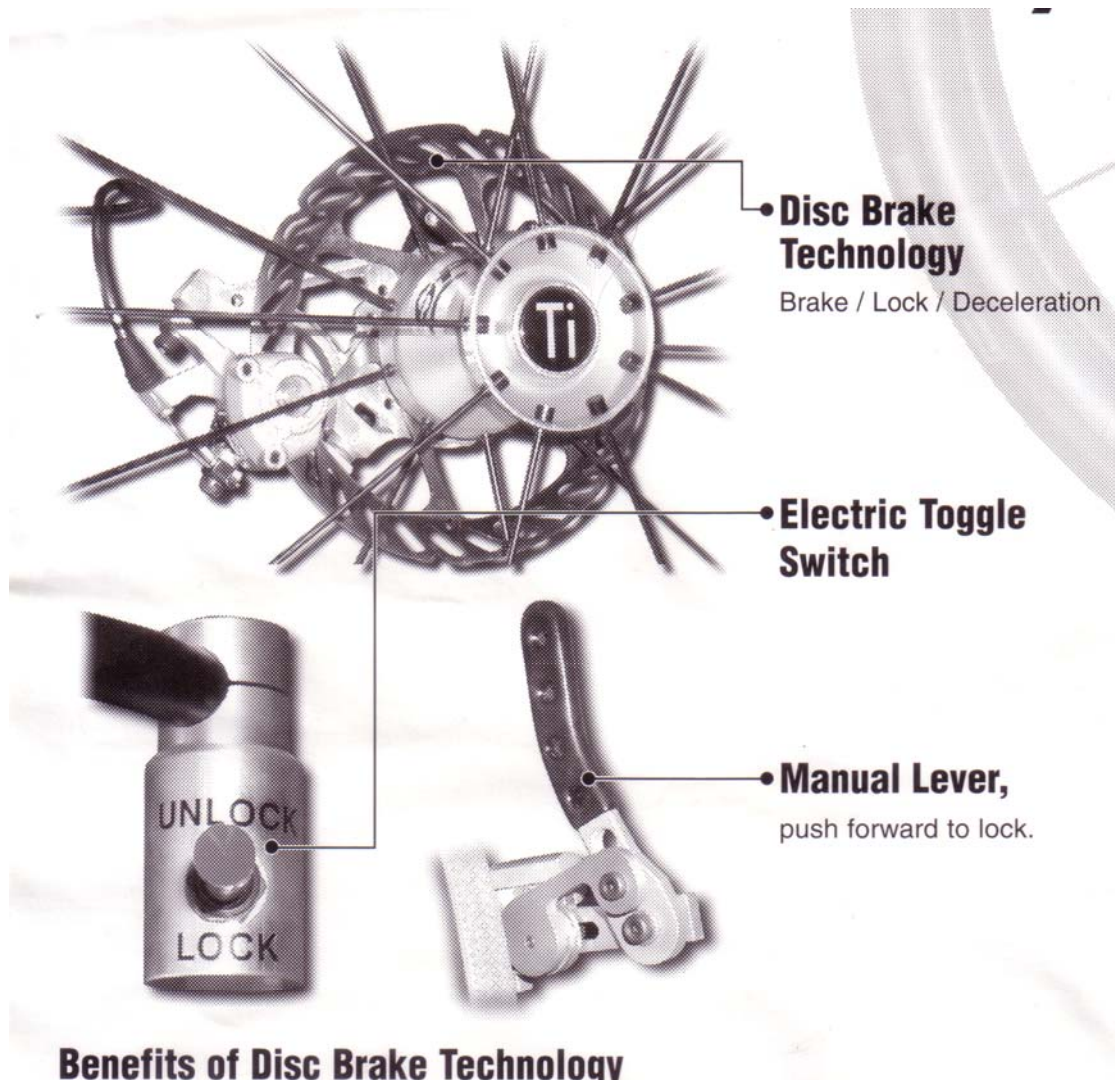


Fig 52. ADI Disc Brakes lock the wheel at the hub.

Design Criterion 4:

The wheelchair will allow for folding.

Implication: A wheelchair with the ability to fold makes it easier to store and transport, easing care staff duties and allows elders to have greater frequency of experiences outside a NH or ALF facility.

Design Opportunity: Reassessing Folding

Solution: Research and sketch possible folding solutions to determine which will best meet the project needs (See Figures 51- 55 and Figure 30).



The Champion 2000's patented folding mechanism prevents flex and shift. It gives the user the ride, stability and support of a rigid chair with all the advantages of a side-to-side folding chair.



The Champion 2000 is the most portable ultralight available because of its fold down back. Quick release wheels enable the Champion to travel in the smallest spaces; even the overhead bin of some commercial aircraft.

Fig 53. Folding: Kuschall Champion

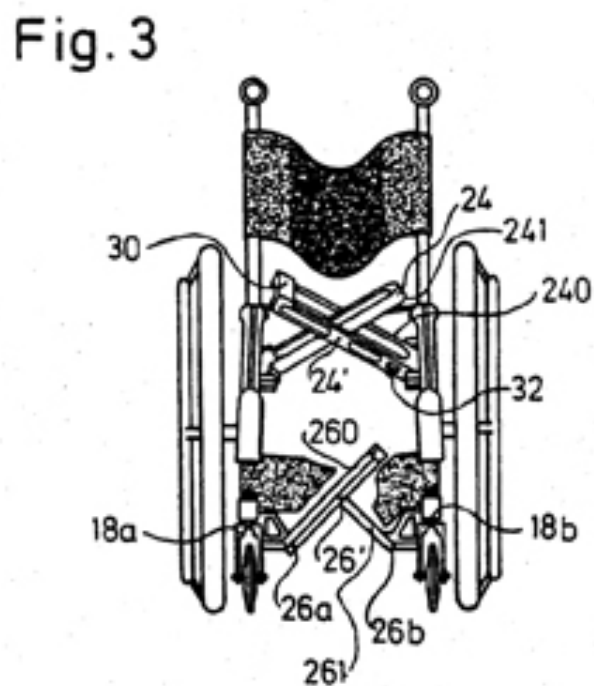
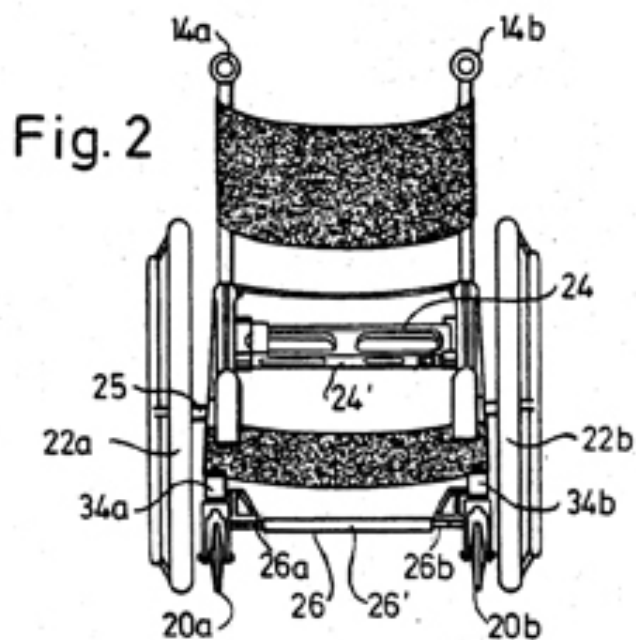


Fig 54. Alternative Kuschall folding method - 1987

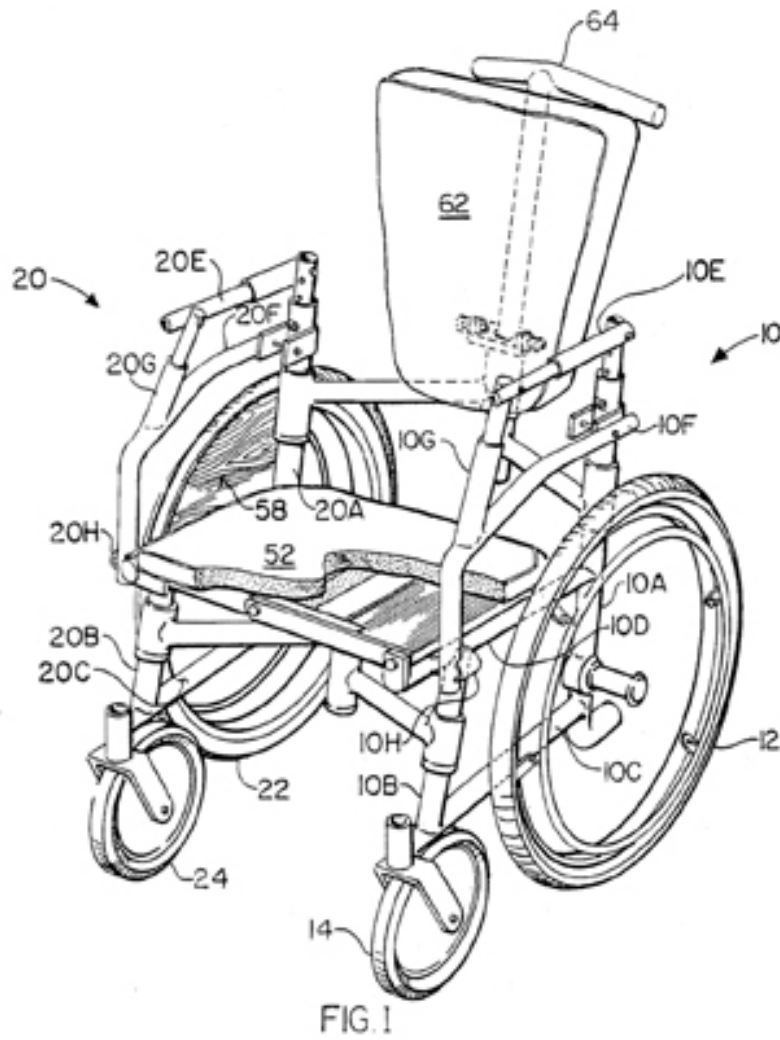


Fig 55. Front Folding Wheelchair Concept – 1987



Compact Folding Frame
The Quickie Revolution's new frame design folds up so small and compact it fits almost anywhere.



Folding Side Guards
No need to remove the Quickie Revolution's side guards when folding the chair—these aluminum side guards automatically fold down with the backrest.

- Weight: 23 lbs.
- Color Options: Blue, Black, Red, Midnight Purple, Teal, Hot Pink, Lavender, Forest Green, Burgundy, Antique Bronze, Camo, Black Diamond, Candy Red, Candy Purple
- Lifetime frame warranty

Fig 56. Sunrise Quickie Revolution Flat Folding Wheelchair Frame

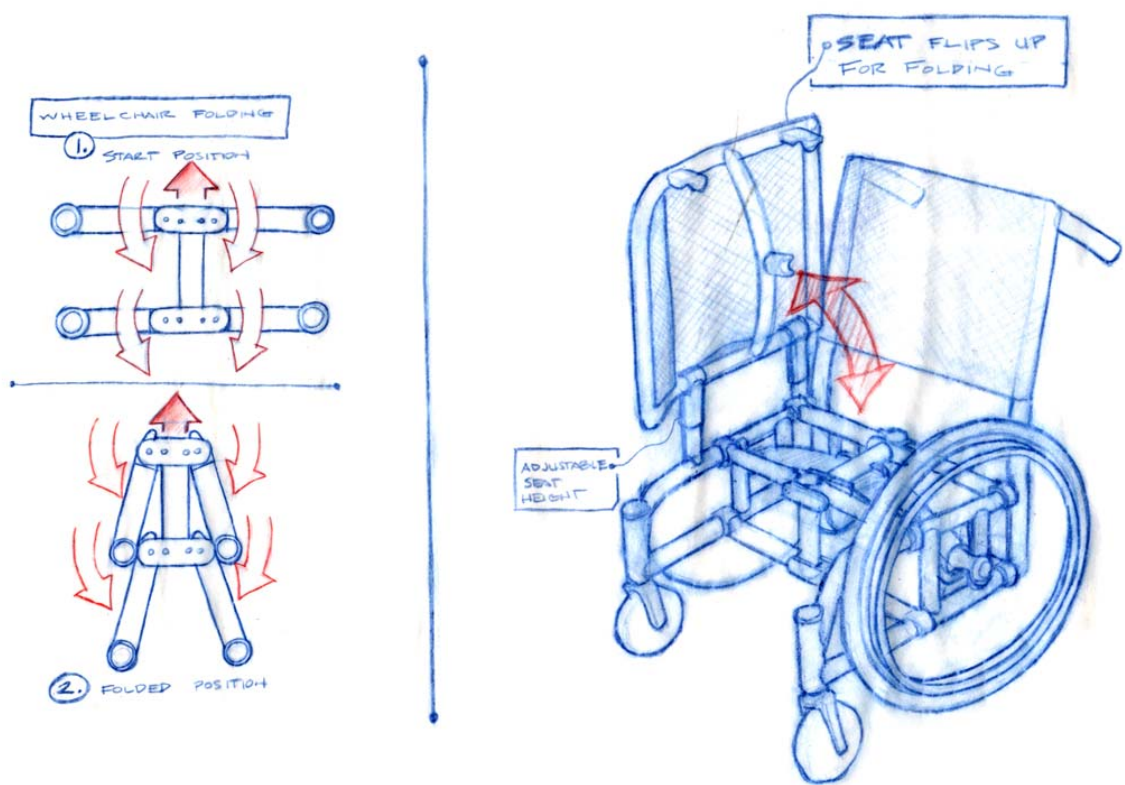


Fig 57. Knuckle Frame Idea

“Nice to Have” Ideas . . .

Tensile/Suspension Seat Development:

- An integrated seating system to the WC frame to improve posture and pressure relief for long term seating. (This may be a retrofit part designed for this wheelchair or it can be purchased as an option at initial purchase.)

Implication from R2b Research: *A wheelchair that provides low maintenance seating with proper postural support, tissue support, and pressure relief is essential for the long-durations of sitting encountered by elder wheelchair users.*

Design Opportunities: *Elders in NH’s are subjected to sling seats until they develop a pressure sore. After pressure ulcers develop, then an NH’s therapy department can justify the purchase of a cushion and solid seat. A better seating solution needs to be integrated into wheelchairs for elders to improve current seating problems and form a preventative means of dealing with pressure ulcers. This is a cost prohibitive item, at this time.*

Solution: Using a tensile seating system concept created by co-developed by Randy Bernard, Ceara Byrne, and Dr. Stephen Sprigle currently under development at CATEA. I sculpted and envisioned how the seat might look and how it could attach to the chassis (see Appendix).

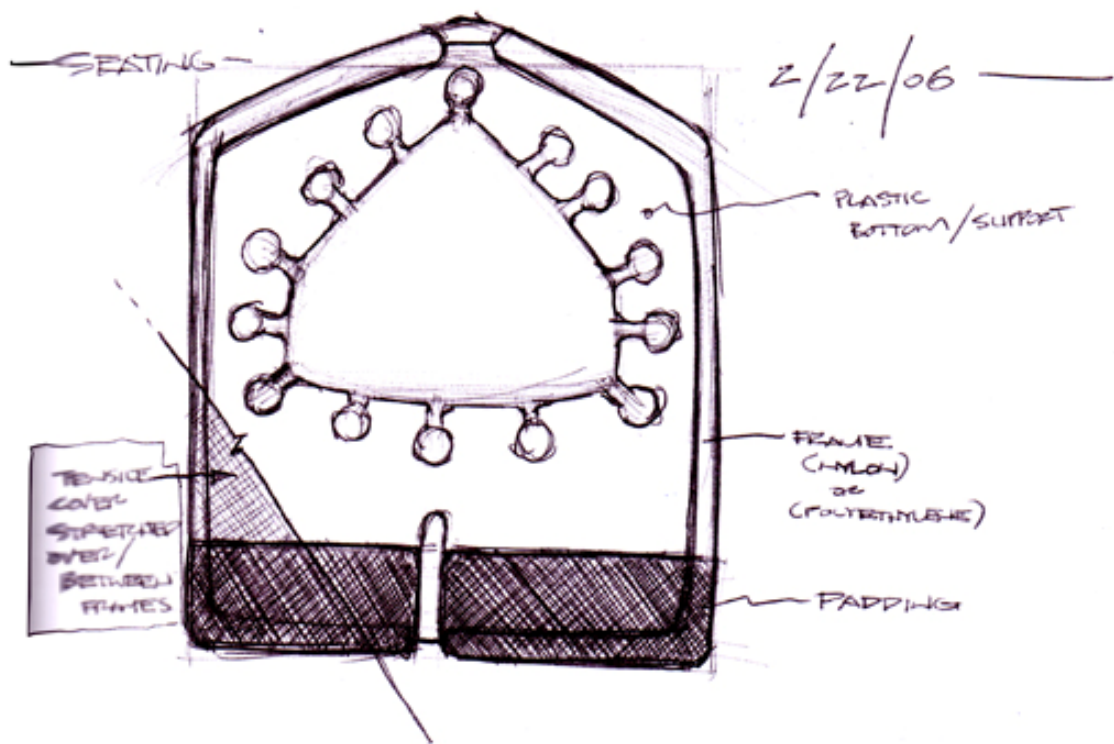


Fig 58. CATEA's Tensile Seat Concept (Inventors: S. Sprigle, R. Bernard and C. Byrne. Rendering and Ideation: Clint Cope Georgia Institute of Technology 2005)



Fig 59. Randy Bernard testing out the tensile seat and bending nose of Herman Miller's 'Mirra' Chair at the Atlanta, GA Design Within Reach store as a potential seating solution for foot/combination propellers.

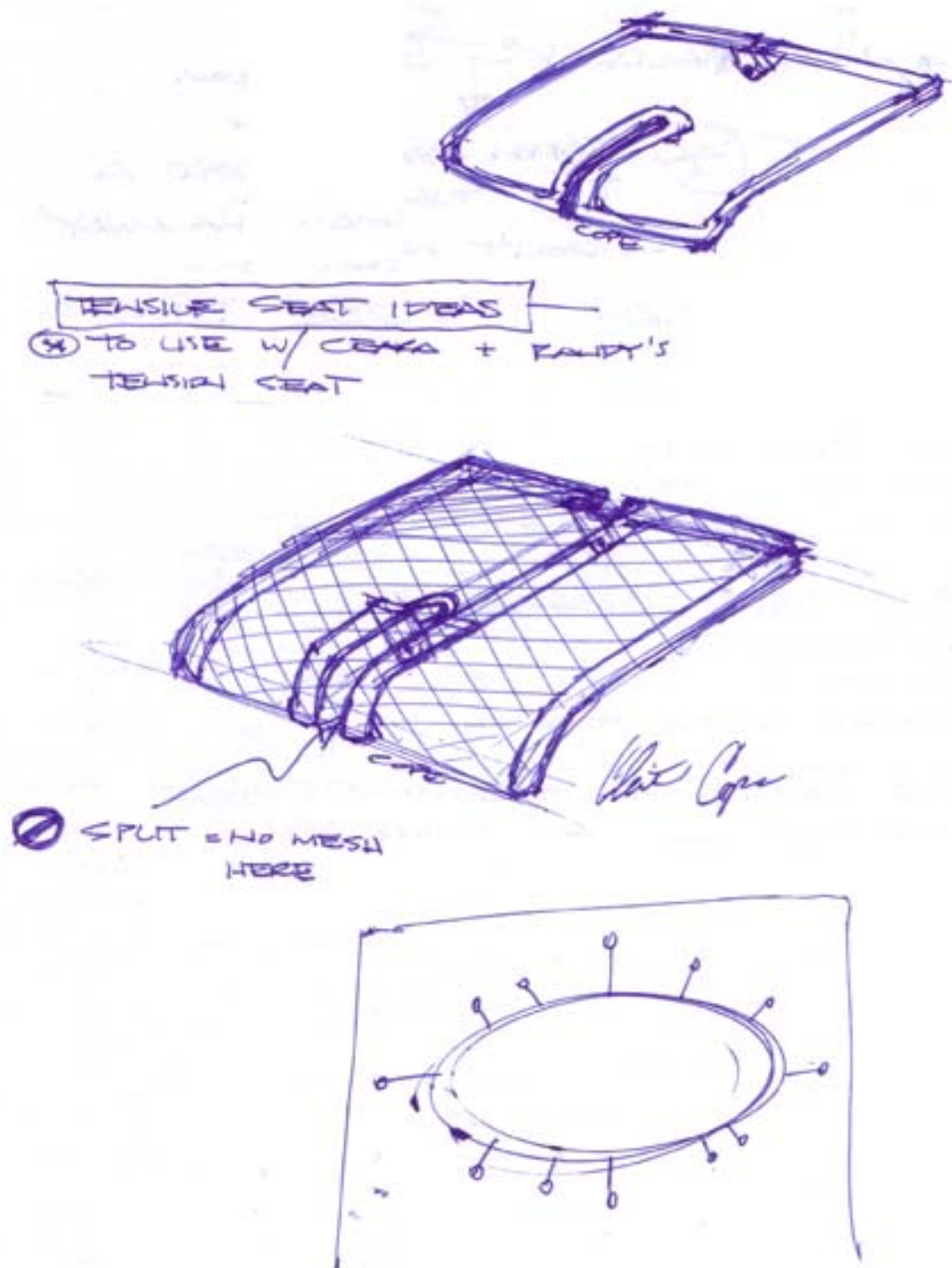


Fig 60. Envisioning a seat to better accommodate foot propulsion

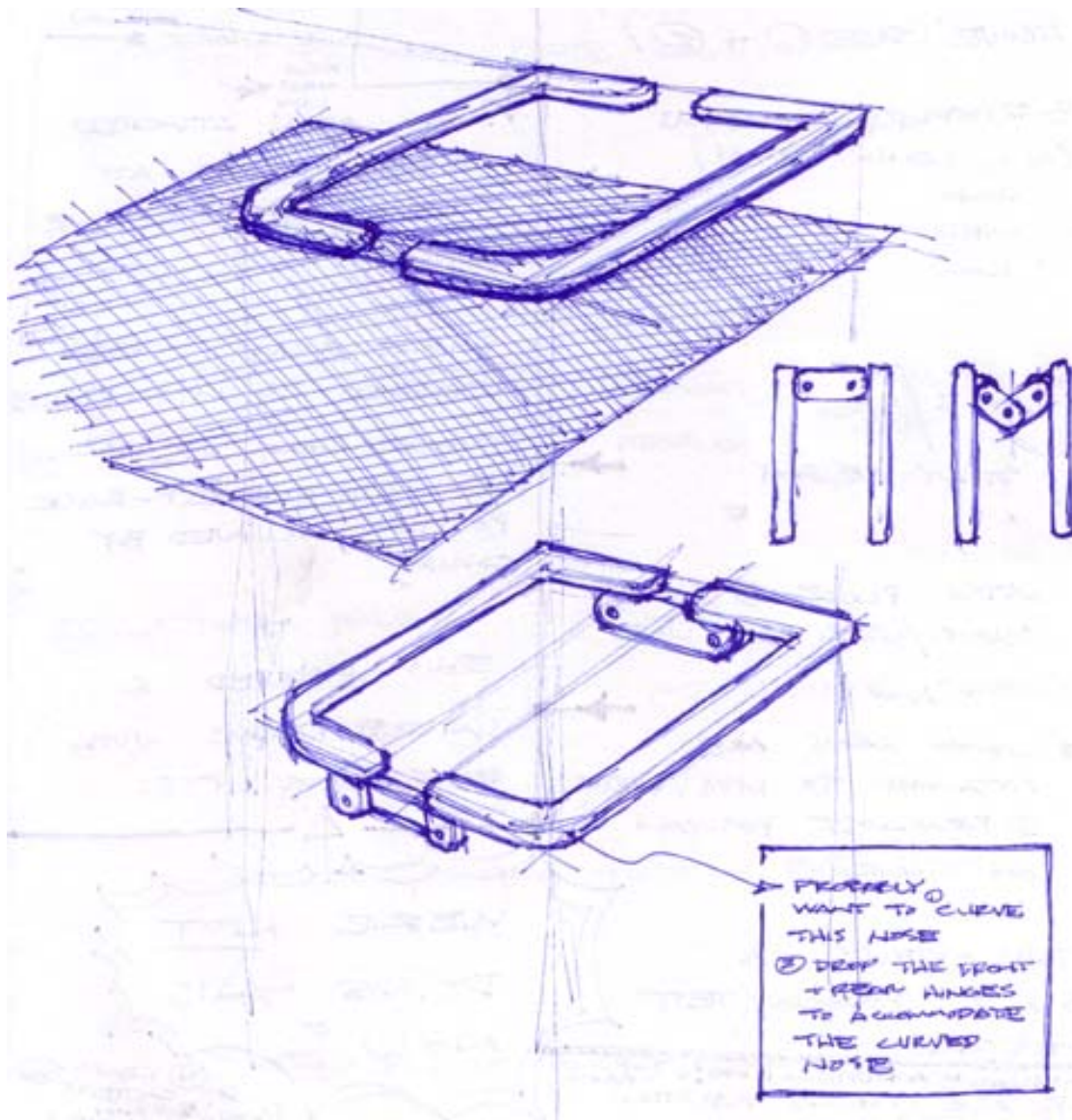


Fig 61. Envisioning Folding

2/12/00

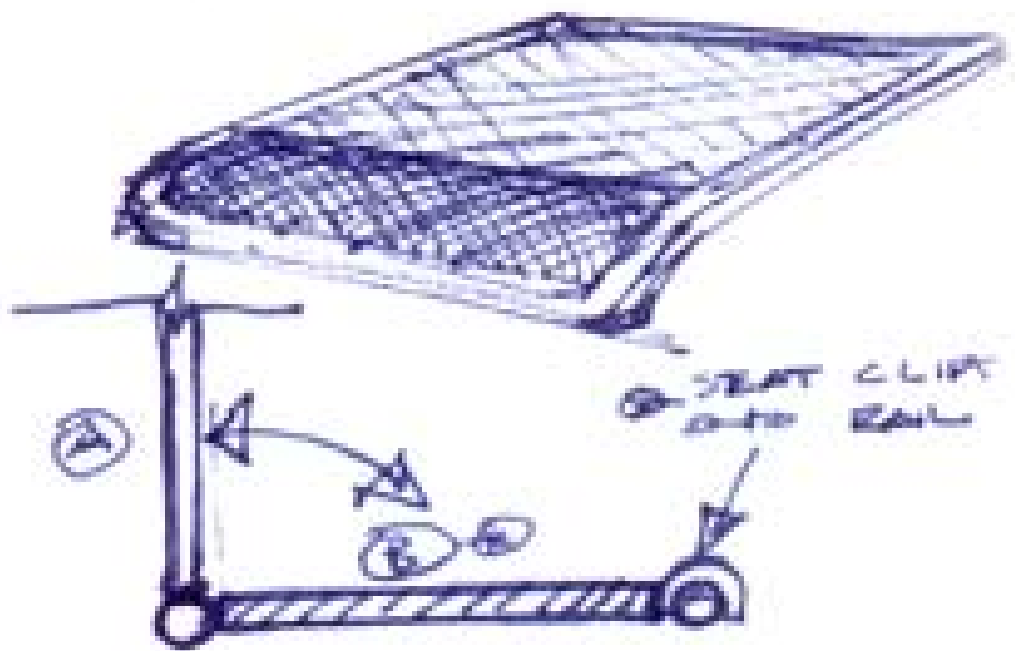


Fig 62. Attachment Method 1

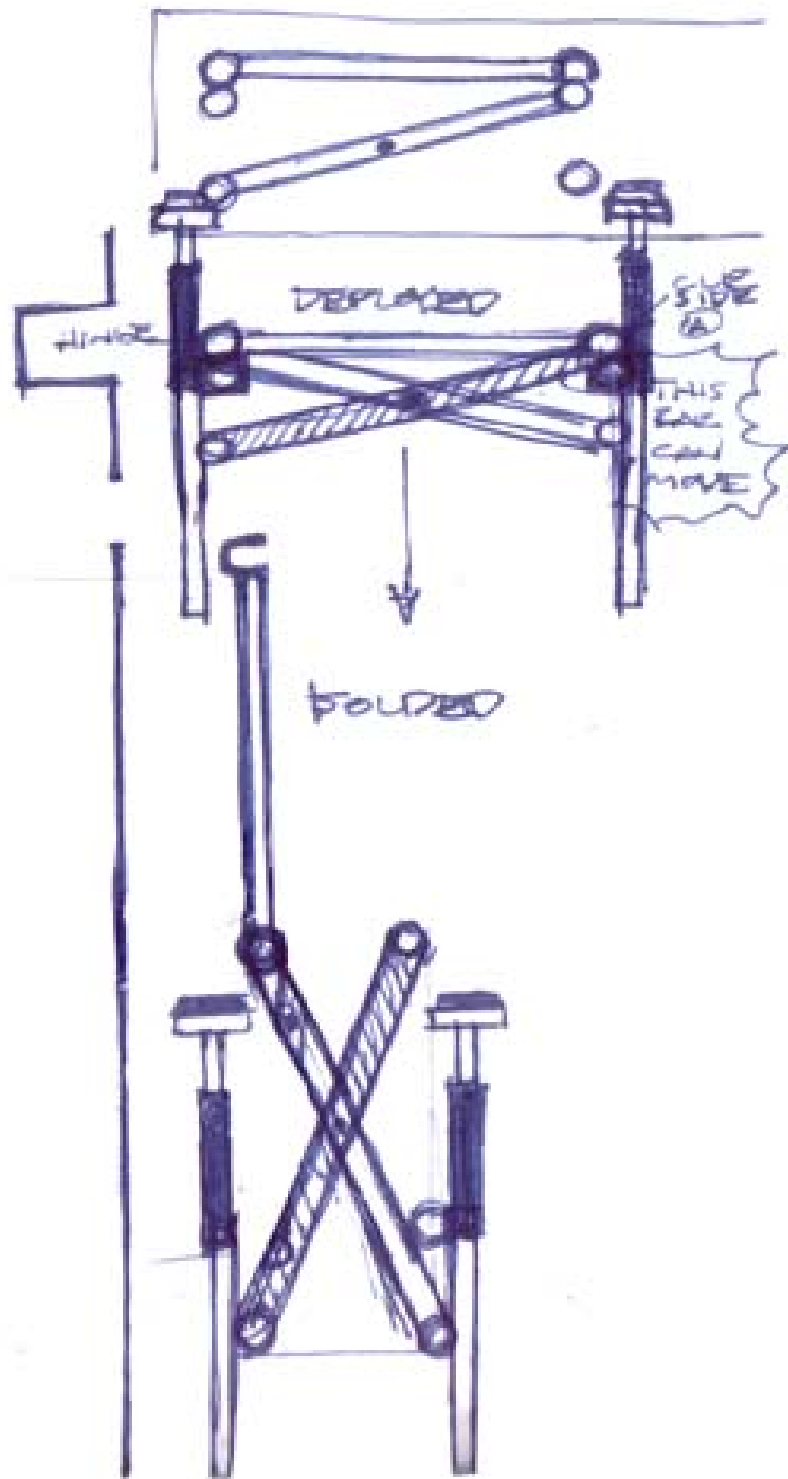


Fig 63. Attachment Method 2

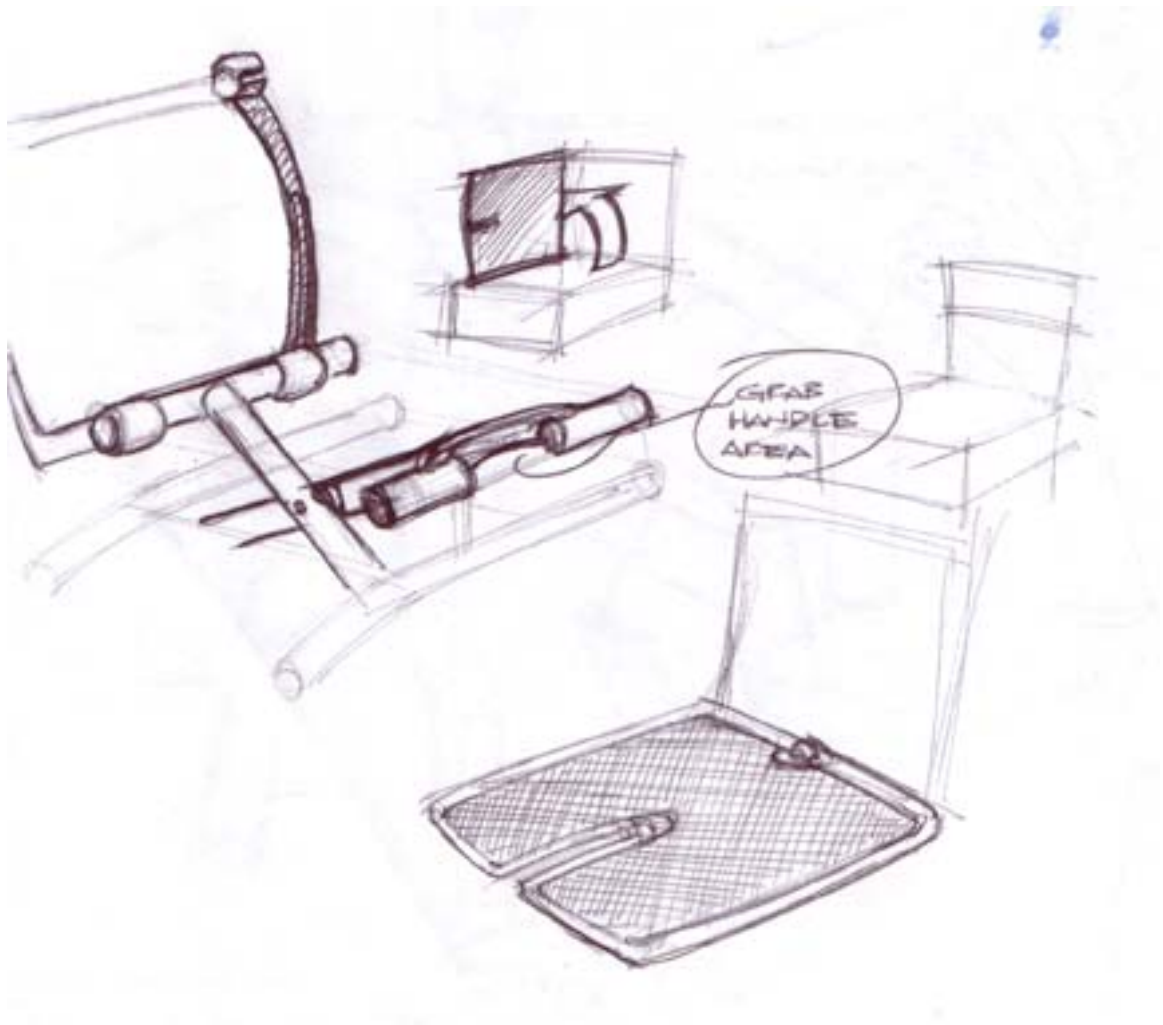


Fig 64. Attachment Method 3

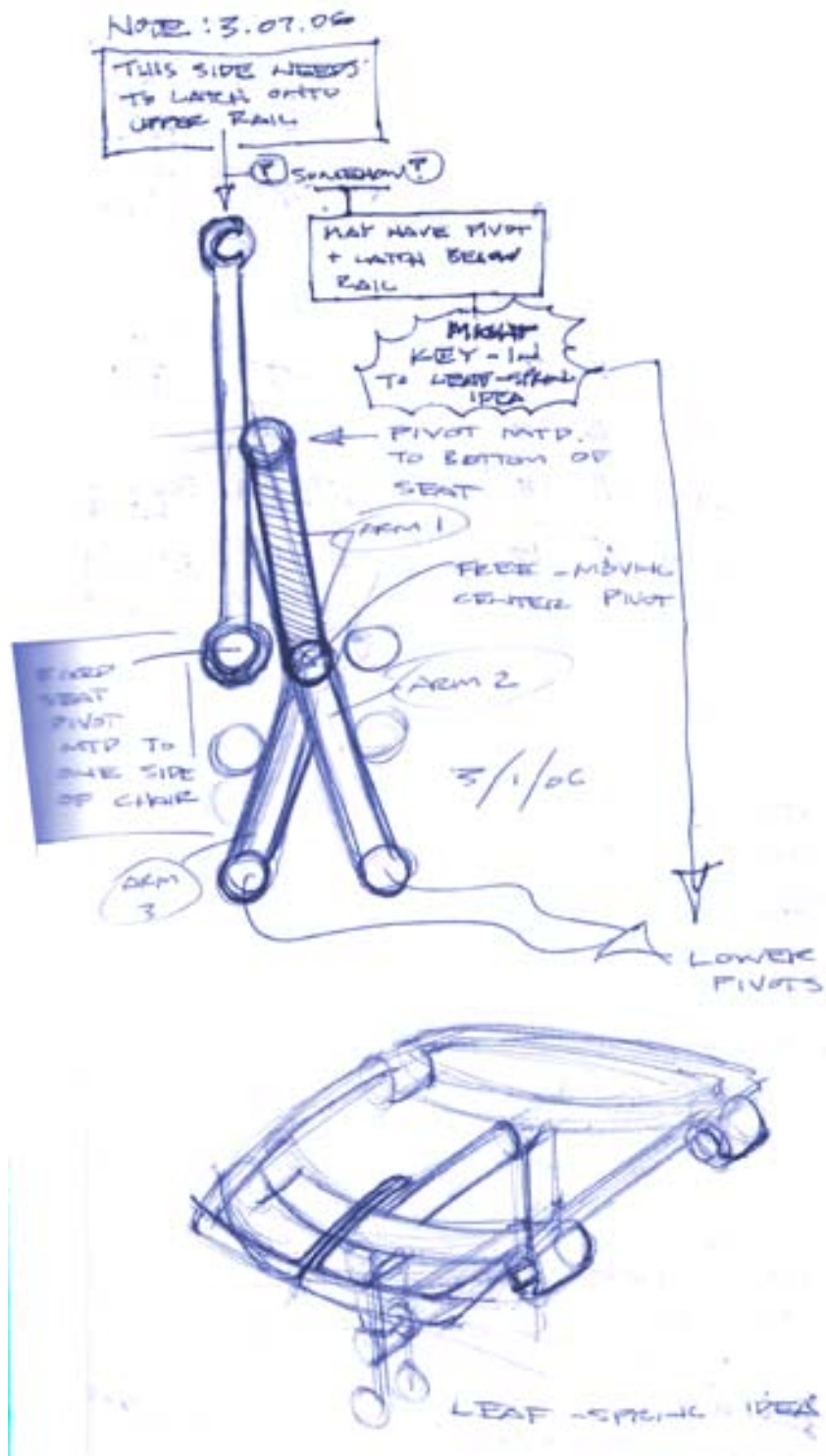


Fig 65. Attachment Method 4

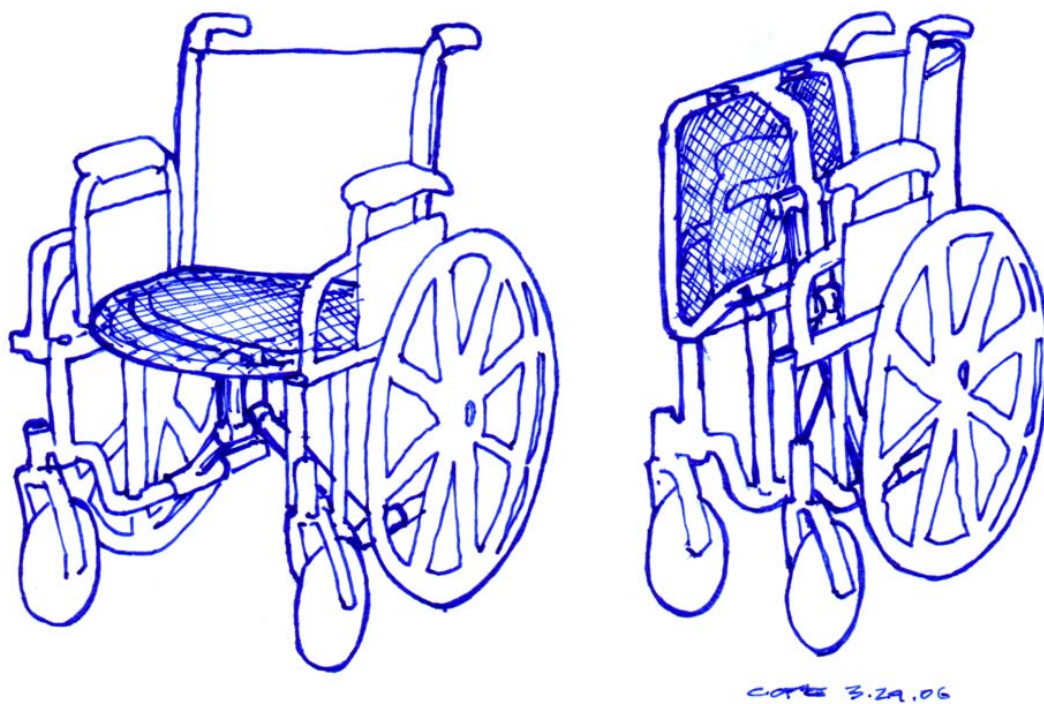


Fig 66. Attachment Method 4 – Unfolded and Folded

- Adjustable footrest length to better accommodate different leg lengths and flexibility needs (See Figure 37).
- Push rims with increased size, larger than typical 50mm diameter (based on anthropometric data for hand grip size and designing for arthritis criteria). Three Rivers Products "Natural Fit" Pushrim meets these needs quite well (see Fig XX), but is cost prohibitive in meeting our \$400.00 price point at this time (Out Front ,2005).

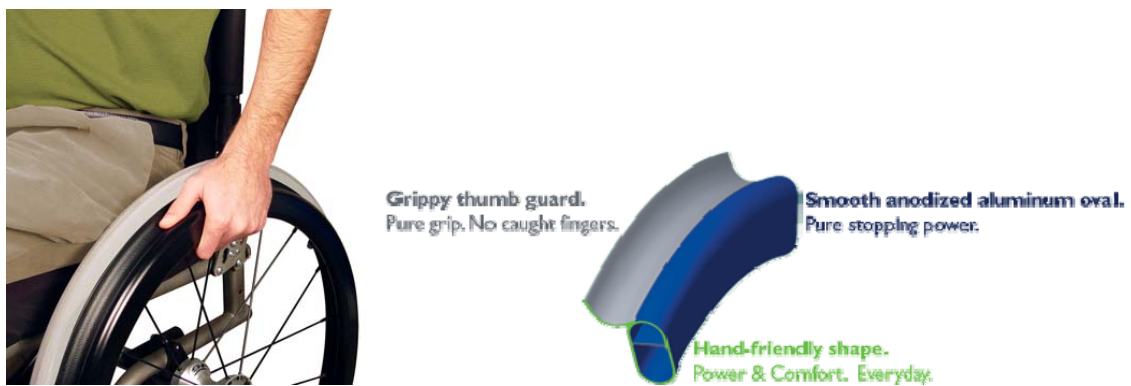


Fig 67. Three Rivers "Natural Fit" Pushrim

APPENDIX A: DATA TABLES

Table 3. Raw Data – AB Obstacle Clearance Study

Elder Wheelchair Project
Swingarm Optimization Pilot Study
AB Population
Clint Cope and Randy Bernard
Results: 2/20/06

ADA Comp. Obst. - Percvd. Effort **Front Casters (Forward)**

On a scale from 1-6, 1 being easy and 6 being difficult, how was it to get the front casters over the obstacle compared to the standard wheelchair (Breezy)?

	Conf ig. 1.1	Conf ig. 2.1	Conf ig. 3.1	Conf ig. 1.2	Conf ig. 2.2	Conf ig. 3.2	
Front Casters (Forward)							axle x.1 2.66 6666 7
Partic. 1	2	2			1	1	axle x.2 1.46 6666 7
Partic. 2	3		2	1		1	sa 1 2
Partic. 3	3	2	2		1		sa 2 2.5
Partic. 4		3	2	1		1	sa 3 1.7
Partic. 5	3		3	1	2		
Partic. 6		4		2	3	1	
Partic. 7	3		2		2	1	
Partic. 8	2	3		1		2	
Partic. 9	4	4	4		3		
Partic. 10		3	1	1		1	
Partic. 11	2		2	2	1		
Partic. 12		4		1	1	1	
Partic. 13	2		2		4	1	
Partic. 14	3	3		2		2	
Partic. 15		3	2	1	1		
Average	2.85					1.14	
Winner	7143	3	2.25	1.25	2	2857	
				X		X	

Drive Wheels (Forward) (Comparative)

On a scale from 1-6, 1 being easy and 6 being difficult, how was it to get the drive wheels over the obstacle compared to the standard wheelchair (Breezy)?

	Conf ig. 1.1	Conf ig. 2.1	Conf ig. 3.1	Conf ig. 1.2	Conf ig. 2.2	Conf ig. 3.2	
Drive Wheels (Forward) (Comparative)							axle x.1 3.73 3333
Partic. 1	5	4			5	6	3
Partic. 2	4		5	5		6	axle x.2 4.33 3333
Partic. 3	4	3	5		4		3
Partic. 4		2	4	3		6	
Partic. 5	4		5	6	4		sa 1
Partic. 6		3		3	3	4	4
Partic. 7	3		3		4	2	sa 2
Partic. 8	4	3		4		5	3.5
Partic. 9	4	4	4		4		sa 3
Partic. 10		3	4	5		5	4.6
Partic. 11	3		5	4	3		
Partic. 12		2		4	4	4	
Partic. 13	1		4		3	5	
Partic. 14	4	4		5		5	
Partic. 15		4	5	5	4		
Average	3.6	3.2	4.4	4.4	3.8	4.8	
Winner	X	X			X		

Drive Wheels (Reverse) (Comparative)

On a scale from 1-6, 1 being easy and 6 being difficult, how was it to get the drive wheels over the obstacle when traveling in reverse compared to the standard wheelchair (Breezy)?

	Conf ig. 1.1	Conf ig. 2.1	Conf ig. 3.1	Conf ig. 1.2	Conf ig. 2.2	Conf ig. 3.2	
Drive Wheels (Reverse) (Comparative)							axle x.1 3.06 6666
Partic. 1	4	5			3	4	7
Partic. 2	4		3	3		4	axle x.2 3.06 6666
Partic. 3	3	3	3		4		7
Partic. 4		2	2	2		2	
Partic. 5	3		3	2	3		sa 1
Partic. 6		5		3	3	3	3

Partic. 7	2		2		4	2	sa 2
Partic. 8	3	3		3		3	3.45
Partic. 9	4	4	5		4		sa 3
Partic. 10		3	2	3		3	2.75
Partic. 11	3		2	3	2		
Partic. 12		3		4	4	4	
Partic. 13	2		1		3	1	
Partic. 14	3	4		4		3	
Partic. 15		3	3	2	4		
Average	3.1	3.5	2.6	2.9	3.4	2.9	
Winner			X	X		X	
	Conf ig. 1.1	Conf ig. 2.1	Conf ig. 3.1	Conf ig. 1.2	Conf ig. 2.2	Conf ig. 3.2	
Overall Results (Comparative - Means)							
FC (Comp)	2.9	3	2.25	1.25	2	1.1	
DW (Fwd) (Comp)	3.6	3.2	4.4	4.4	3.8	4.8	
DW (Rev) (Comp)	3.1	3.5	2.6	2.9	3.4	2.9	
		3.23	3.08		3.06	2.93	
		3333	3333		6666	3333	
Average	3.2	3	3	2.85	7	3	
Winner				X		X	

Rear Casters (Reverse) (Non-Comparative)

Are you able to get the rear casters ove the obstacle?

(* = can get over obstacle w/a 6" running start
(runup)before obstacle)

Rear Casters (Reverse) (Non-Comparative)

	Conf ig. 1.1	Conf ig. 2.1	Conf ig. 3.1	Conf ig. 1.2	Conf ig. 2.2	Conf ig. 3.2
Partic. 1						
Partic. 2						
Partic. 3	N*	N*			N*	N*
Partic. 4	N*		N*	N*		N*
Partic. 5	N*	N*	Y		N*	
Partic. 6		N*	N*	N*		N*
Partic. 7	N*		N*	N*	N*	
Partic. 8		Y		N*	N*	N*
Partic. 9	N*		Y		Y	N*
Partic. 10	N*	N*		N*		N*
Partic. 11	N*	N*	N*		N*	
Partic. 12		N*	N*	N*		N*
Partic. 13	N*		N*	N*	N*	
Partic. 14		N*		N*	N*	N*
Partic. 15	N*		N*		N*	N*

Winner	N*	N*		N*		N*
		N*	N*	N*	N*	

Favorite

Out of all the chairs that you tested today, what was your favorite?

... Why?

Favorite

	Conf ig. 1.1	Conf ig. 2.1	Conf ig. 3.1	Conf ig. 1.2	Conf ig. 2.2	Conf ig. 3.2	Bree zy
Partic. 1							
Partic. 2							
Partic. 3		X					
Partic. 4			X				
Partic. 5					X		
Partic. 6		X					
Partic. 7					X		
Partic. 8						X	
Partic. 9						X	
Partic. 10						X	
Partic. 11							X
Partic. 12			X				
Partic. 13			X				
Partic. 14				X			
Partic. 15					X		
Winner					X		X

Least Favorite

Out of all the chairs that you tested today, what was your least favorite? . .

<i>. Why?</i>	0	2	3	1	4	3	2
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Least Favorite

	Conf ig. 1.1	Conf ig. 2.1	Conf ig. 3.1	Conf ig. 1.2	Conf ig. 2.2	Conf ig. 3.2	Bree zy
Partic. 1							
Partic. 2							
Partic. 3						X	
Partic. 4				X			
Partic. 5			X				
Partic. 6						X	
Partic. 7				X			
Partic. 8		X					
Partic. 9			X				
Partic. 10				X			
Partic. 11					X		
Partic. 12						X	

Partic. 13							X
Partic. 14						X	
Partic. 15						X	
						X	
Loser				X			
				X		X	
Overall Results (Comb. w/ user feedback)							
(X** = Individual Task Ratings & User Feedback Used to Identify Potential Wheelchairs)							
FC (Comp)	0	1	2	4	1	6	1
DW (Fwd) (Comp)	Conf	Conf	Conf	Conf	Conf	Conf	
DW (Rev) (Comp)	ig.	ig.	ig.	ig.	ig.	ig.	
	1.1	2.1	3.1	1.2	2.2	3.2	
	2.9	3	2.25	1.25	2	1.1	
Average	3.6	3.2	4.4	4.4	3.8	4.8	
Winner	3.1	3.5	2.6	2.9	3.4	2.9	
		3.23	3.08		3.06	2.93	
		3333	3333		6666	3333	
	3.2	3	3	2.85	7	3	
		X**	X**		X		
number mentioned as MOST favorite							
number mentioned as LEAST favorite							
	0	2	3	1	4	3	2
	0	1	2	4	1	6	1
	Conf	Conf	Conf	Conf	Conf	Conf	
	ig.	ig.	ig.	ig.	ig.	ig.	
	1.1	2.1	3.1	1.2	2.2	3.2	breezy

Table 4. Mann Whitney Analysis – AB Obstacle Clearance Study

For multiple Mann-Whitney tests, a correction in the alpha level must be done

For a significance of 0.05 and 3 comparisons, the new alpha level is 0.01666

For a significance of 0.1 and 3 comparisons, the new alpha level is 0.03333

3/5/2006 7:41:02 PM

Welcome to Minitab, press F1 for help.

Executing from file: C:\Program Files\MINITAB 14\MACROS\STARTUP.MAC

This Software was purchased for academic use only.

Commercial use of the Software is prohibited.

Mann-Whitney Test and CI: drive-fwd2, drive-fwd3

	N	Median
drive-fwd2	20	4.0000
drive-fwd3	20	5.0000

Point estimate for ETA1-ETA2 is -1.0000

95.0 Percent CI for ETA1-ETA2 is (-2.0000,-1.0003)

W = 284.0

Test of ETA1 = ETA2 vs ETA1 < ETA2 is significant at 0.0003

The test is significant at 0.0002 (adjusted for ties)

Mann-Whitney Test and CI: drive-fwd2, drive-fwd3

	N	Median
drive-fwd2	20	4.0000
drive-fwd3	20	5.0000

Point estimate for ETA1-ETA2 is -1.0000

3.2 Percent CI for ETA1-ETA2 is (-1.0001,-1.0000)

W = 284.0

Test of ETA1 = ETA2 vs ETA1 < ETA2 is significant at 0.0003

The test is significant at 0.0002 (adjusted for ties)

Mann-Whitney Test and CI: drive-fwd2, drive-fwd1

	N	Median
drive-fwd2	20	4.0000
drive-fwd1	20	4.0000

Point estimate for ETA1-ETA2 is -1.0000
 98.5 Percent CI for ETA1-ETA2 is (-0.9999,-0.0002)
 W = 344.5
 Test of ETA1 = ETA2 vs ETA1 < ETA2 is significant at 0.0394
 The test is significant at 0.0296 (adjusted for ties)

Mann-Whitney Test and CI: drive-fwd1, drive-fwd3

	N	Median
drive-fwd1	20	4.000
drive-fwd3	20	5.000

Point estimate for ETA1-ETA2 is -1.000
 98.5 Percent CI for ETA1-ETA2 is (-1.000,0.000)
 W = 342.0
 Test of ETA1 = ETA2 vs ETA1 < ETA2 is significant at 0.0339
 The test is significant at 0.0273 (adjusted for ties)

The results indicated that
 config #2 < config#3
 config#2 is not < config#1 at 0.05 but is at 0.1
 config#1 is not < config#3 at 0.05 but is at 0.1

Mann-Whitney Test and CI: casters-fwd3, casters-fwd2

	N	Median
casters-fwd3	20	2.000
casters-fwd2	20	3.000

Point estimate for ETA1-ETA2 is -1.000
 98.5 Percent CI for ETA1-ETA2 is (-2.000,0.000)
 W = 326.0
 Test of ETA1 = ETA2 vs ETA1 < ETA2 is significant at 0.0120
 The test is significant at 0.0091 (adjusted for ties)

Mann-Whitney Test and CI: casters-fwd3, casters-fwd1

	N	Median
casters-fwd3	20	2.0000

casters-fwd1 20 2.0000

Point estimate for ETA1-ETA2 is 0.0000
98.5 Percent CI for ETA1-ETA2 is (-0.9998,0.0001)
W = 372.0
Test of ETA1 = ETA2 vs ETA1 < ETA2 is significant at 0.1552
The test is significant at 0.1383 (adjusted for ties)

Mann-Whitney Test and CI: casters-fwd1, casters-fwd2

	N	Median
casters-fwd1	20	2.000
casters-fwd2	20	3.000

Point estimate for ETA1-ETA2 is -1.000
98.5 Percent CI for ETA1-ETA2 is (-1.000,0.000)
W = 357.0
Test of ETA1 = ETA2 vs ETA1 < ETA2 is significant at 0.0778
The test is significant at 0.0698 (adjusted for ties)

The results indicate that
Config#3 < config#2
But config#3 is NOT < config#1 & config#1 is NOT < config#2

Mann-Whitney Test and CI: drive-rev3_1, drive-rev2

	N	Median
drive-rev3_1	20	3.000
drive-rev3	20	3.000

Point estimate for ETA1-ETA2 is -1.000
98.5 Percent CI for ETA1-ETA2 is (-1.000,-0.000)
W = 330.5
Test of ETA1 = ETA2 vs ETA1 < ETA2 is significant at 0.0163
The test is significant at 0.0121 (adjusted for ties)

Mann-Whitney Test and CI: drive-rev3_1, drive-rev1

	N	Median
drive-rev3_1	20	3.000
drive-rev1	20	3.000

Point estimate for ETA1-ETA2 is -0.000

98.5 Percent CI for ETA1-ETA2 is (-1.000,-0.000)
W = 377.5
Test of ETA1 = ETA2 vs ETA1 < ETA2 is significant at 0.1934
The test is significant at 0.1781 (adjusted for ties)

Mann-Whitney Test and CI: drive-rev1, drive-rev2

	N	Median
drive-rev1	20	3.0000
drive-rev3	20	3.0000

Point estimate for ETA1-ETA2 is 0.0000
98.5 Percent CI for ETA1-ETA2 is (-0.9997,0.0002)
W = 352.5
Test of ETA1 = ETA2 vs ETA1 < ETA2 is significant at 0.0616
The test is significant at 0.0483 (adjusted for ties)

The results indicate that
Config#3 < config#2
BUT config#3 is NOT < config#1 & config#1 is NOT < config#2

So, in summary

Drive wheels forward: #2 easier than #1 which is easier than #3
Casters forward: #3 is easier than #2 but not easier than #1; in addition, #1 is not necessarily easier than #2
Drive wheels reverse: #3 is easier than #2 but not easier than #1; in addition, #1 is not necessarily easier than #2

Table 5. Kruskal Wallis Analysis – AB Obstacle Clearance Study

Kruskal-Wallis Test: fwd drive score versus axle position

Kruskal-Wallis Test on fwd drive score

axle position	N	Median	Ave Rank	Z
1	30	4.000	26.0	-1.99
2	30	4.000	35.0	1.99
Overall	60		30.5	

H = 3.95 DF = 1 P = 0.047

H = 4.37 DF = 1 P = 0.036 (adjusted for ties)

DIFFERENCE BETWEEN AXLE POSITION IN FORWARD DRIVE WHEEL CLIMBING

Kruskal-Wallis Test: fwd caster versus axle position

Kruskal-Wallis Test on fwd caster

axle position	N	Median	Ave Rank	Z
1	30	3.000	41.2	4.75
2	30	1.000	19.8	-4.75
Overall	60		30.5	

H = 22.52 DF = 1 P = 0.000

H = 24.77 DF = 1 P = 0.000 (adjusted for ties)

DIFFERENCE BETWEEN AXLE POSITION IN FORWARD CASTER CLIMBING

Kruskal-Wallis Test: rev drive versus axle position

Kruskal-Wallis Test on rev drive

axle position	N	Median	Ave Rank	Z
1	30	3.000	29.9	-0.26
2	30	3.000	31.1	0.26
Overall	60		30.5	

H = 0.07 DF = 1 P = 0.796

H = 0.08 DF = 1 P = 0.783 (adjusted for ties)

NO DIFFERENCE IN AXLE POSITION IN REVERSE DRIVE WHEEL CLIMBING

Kruskal-Wallis Test: drive-fwd versus swingarm

Kruskal-Wallis Test on drive-fwd

swingarm	N	Median	Ave Rank	Z
1	20	4.000	30.4	-0.04
2	20	4.000	20.9	-3.00
3	20	5.000	40.2	3.04
Overall	60		30.5	

H = 12.18 DF = 2 P = 0.002

H = 13.48 DF = 2 P = 0.001 (adjusted for ties)

DIFFERENCE IN SWINGARM CONFIG IN FORWARD DRIVE WHEEL CLIMBING
BASED UPON Z SCORES, CONFIG#2 IS EASIER THAN CONFIG#3
A MULTIPLE COMPARISON TEST CAN CONFIRM

Kruskal-Wallis Test: casters-fwd versus swingarm

Kruskal-Wallis Test on casters-fwd

swingarm	N	Median	Ave Rank	Z
1	20	2.000	29.8	-0.24
2	20	3.000	37.4	2.15
3	20	2.000	24.4	-1.91
Overall	60		30.5	

H = 5.55 DF = 2 P = 0.062

H = 6.11 DF = 2 P = 0.047 (adjusted for ties)

DIFFERENCE IN SWINGARM CONFIG IN FORWARD CASTER CLIMBING
BASED UPON Z SCORES, CONFIG#3 IS EASIER THAN CONFIG#2
A MULTIPLE COMPARISON TEST CAN CONFIRM

Kruskal-Wallis Test: drive-rev versus swingarm

Kruskal-Wallis Test on drive-rev

swingarm	N	Median	Ave Rank	Z
1	20	3.000	29.3	-0.39
2	20	3.000	37.4	2.15
3	20	3.000	24.9	-1.76
Overall	60		30.5	

H = 5.24 DF = 2 P = 0.073
H = 5.93 DF = 2 P = 0.052 (adjusted for ties)

DIFFERENCE IN SWINGARM CONFIG IN REVERSE DRIVE WHEEL CLIMBING
BASED UPON Z SCORES, CONFIG#3 IS EASIER THAN CONFIG#2
A MULTIPLE COMPARISON TEST CAN CONFIRM

Kruskal-Wallis Test: drive-fwd_1 versus config_1

Kruskal-Wallis Test on drive-fwd_1

config_1	N	Median	Ave Rank	Z
1	10	4.000	24.5	-1.19
2	10	3.000	16.4	-2.80
3	10	4.500	37.2	1.32
4	10	4.500	36.3	1.14
5	10	4.000	25.5	-1.00
6	10	5.000	43.3	2.53
Overall	60		30.5	

H = 16.40 DF = 5 P = 0.006
H = 18.14 DF = 5 P = 0.003 (adjusted for ties)

DIFFERENCE IN WHEELCHAIR CONFIG IN FORWARD DRIVE WHEEL CLIMBING
BASED UPON Z SCORES, CONFIG#6 IS EASIER THAN CONFIG#2
OTHER POTENTIAL DIFFERENCES REQUIRE A MULTIPLE COMPARISON TEST;

Kruskal-Wallis Test: caster-fwd versus config_1

Kruskal-Wallis Test on caster-fwd

config_1	N	Median	Ave Rank	Z
1	10	3.000	42.4	2.35
2	10	3.000	47.6	3.38
3	10	2.000	33.7	0.63
4	10	1.000	17.2	-2.65
5	10	1.500	27.2	-0.66
6	10	1.000	15.1	-3.05
Overall	60		30.5	

H = 28.46 DF = 5 P = 0.000
H = 31.30 DF = 5 P = 0.000 (adjusted for ties)

DIFFERENCE IN WHEELCHAIR CONFIG IN FORWARD CASTER CLIMBING
BASED UPON Z SCORES, CONFIGS #1&2 ARE EASIER THAN CONFIGS#4&6
OTHER POTENTIAL DIFFERENCES REQUIRE A MULTIPLE COMPARISON TEST;

Kruskal-Wallis Test: drive-rev_1 versus config_1

Kruskal-Wallis Test on drive-rev_1

config_1	N	Median	Ave Rank	Z
1	10	3.000	31.3	0.16
2	10	3.000	37.2	1.33
3	10	2.500	21.3	-1.83
4	10	3.000	27.2	-0.65
5	10	3.500	37.5	1.39
6	10	3.000	28.6	-0.39
Overall	60		30.5	

H = 6.39 DF = 5 P = 0.270

H = 7.23 DF = 5 P = 0.204 (adjusted for ties)

NO DIFFERENCES IN WHEELCHAIR CONFIG IN REVERSE DRIVE WHEEL
CLIMBING

Table 6. User Feedback/Comments – AB Obstacle Clearance Study

Clint Cope
Elder Wheelchair Development Pilot Study
User Comments
Transcribed 3-8-06

Q: Compared to the Breezy, how did wheelchair _____ compare?

FC

1.2

Partic 8: “I’m popping a wheelie instantly with this chair.”

Partic 14: “It’s not as stable as the Breezy. It turns and twists, but not as badly as the first one (3.2).

2.1

Partic 6: “There’s a noticeable clunk when the front casters go over. It’s slightly harder than the Breezy to get over a bump. It requires ‘2 pushes’ to get over the bump (one initial push to get the front casters over and a second push to get the drive wheels over).”

Partic 8: “ It does what the first one does (3.2) without the upwards wheelie.

Partic 14: “

3.1

Partic 4: “Seems like the split difference between the 2 of them (2.1 and 3.2). Still has a little bit of ‘pop’ (ability to pop a wheelie easily) but not as much as the 2nd (3.2).

Partic 5: “This feels a little wobblier (than the Breezy). It feels less stable. When I go over, the axles ‘feel detached.’ (User explained this as one axle getting over the obstacle before the other). It wobbles a bit when I go over.

Partic 7: “Tippy. (This chair has a) slight initial sense of that.”

1.2

Partic 2: “ It causes some anxiety when first popping-up over the obstacle.”

Partic 6: “I just have to shift my weight back slightly and I can be ‘weightless’. The front casters lift up. This is slightly disconcerting at first. It happens when I push forward and not when I’m standing still.

3.2

Partic 1: “I don’t like how I tip back even with the slightest pushing and no obstacle”

Partic 4: “From a standing start, it’s really easy to go into a wheelie, but precarious. It’s easy to wheelie in a nervous way (user smiles).

Partic 8: “Surprising that one push puts you into a wheelie. It’s slightly disconcerting, but you get used to it. I still feel comfortable going over the obstacle.” <Note: Semi-skilled user, has good postural control.>

Partic 13: “ Whoa! Rear tippy.”

Partic 14: “The front casters are much easier than the Breezy.”

DWF

1.1

Partic1: “When I went over with the drive wheels this felt less stable (than the Breezy). It tilts slightly. It has a ‘front lift.’” (Wheels want to lift as participant propels forward over the obstacle).

Partic1: “It tilts-up a bit when going over the obstacle when using the drive wheels. It’s surprising! It makes me feel like it shouldn’t do that.”

Partic1: “Feels more difficult to push forward over the obstacle than the last chair (2.1) and the Breezy.”

Partic 5: “Feels like it takes a little more force (than the Breezy) to get over it (the obstacle), but it’s better than the 2nd chair (1.2).

Partic 7: “It’s nicer that it doesn’t ‘kick-up’ (instantly want to go into a wheelie when the drive wheels are pushed) like some others. It stays down and feels more stable it is one of the better chairs

Partic. 11: “I like the drive wheel position (ant.-post.) better than the Breezy in going over obstacles.”

Partic. 13: “It’s much easier to maneuver than the Breezy.”

1.2

Partic 2: “I started to realize that moving my upper body begins to make a difference in feeling (stable) when going over the obstacle.”

Partic 5: “This one’s like lifting weights. I have to push then really push to get over the obstacle. It feels smoother than the previous chair, but tense! I can’t get over the obstacle without pushing (hard).”

Partic 11: “It wants to tilt (go into a wheelie) when you ‘hit’ (push forward on) the drive wheels. I know that the (stops on the) casters are there, but I’m always in a wheelie.

“I like the wheel position (ant.-post.).”

Partic 12: “This is scarier and harder. It rocks a bit”

Partic 14: “ It’s a little hard (to push)going forward.”

Partic 15: “ The drive wheels have a noticeable mechanical shift when going over the obstacle. It seems like the rolling resistance of the drive wheels is lower than the Breezy. I felt more secure in going over the obstacle in the Breezy. This wheelchair requires less effort than 3.1.”

2.1

Partic 1: “This chair feels fine. Good stability!”

Partic 4: “Just having the axles further forward gives me more fine control over the bump. The arm position seems more comfortable (than the Breezy). I have better range of motion.

Partic 14: “It’s similar to the Breezy. It’s feels comfortable. It doesn’t want to turn as much, so it feels stable.”

Partic 15: “This seems similar to the Breezy. It has better stability than the Breezy.”

2.2

Partic 1: “It also tilts up a bit when going over the obstacle. It’s a similar experience to the last experimental chair, but lifts more than the last one (1.1).”

Partic 11: “The wheels are a bit far forward, but it rolled the best over the obstacle.”

Partic 12: “It seems harder (to push over the obstacle).”

Partic 15: “This chair is more tippy during normal propulsion. It feels tippy, but not as tippy as the last one (3.1). It catches you earlier (than 3.1).

3.1

Partic 5: “It feels like I have to exert more force to get over the obstacle (than the Breezy).

Partic. 7: “‘Kickup’ (wanting to pop a wheelie) makes it harder to get the drive wheels over an obstacle from a stop. Once you get used to it, the kickup feels OK.”

Partic 15: “This is tippy, but not the same as the first (1.2). The mechanical shift feels more tippy on this one than the others. You have an unstable feeling for a longer period as you wait for the wheelchair to hit the stops.”

3.2:

Partic 1: “I don’t like how I’m tipping when going over the obstacle.”

Partic 2: “I hardly felt that I went over the obstacle.” <Note: Skilled user, can pop wheelies and make torso adjustments.>

Partic 4: “The wheelie factor makes it scary.”

Partic 6: “It’s much easier to turn (than the Breezy). It felt like the drive wheels could ‘move separately’ (one wheel can get over the bump before the other). The standard wheelchair feels like the wheels are connected.”

Partic 7: “I noted ‘kick-up’ (wheelchair wants to pop a wheelie) when starting off. The locks (stops) make it seem less scary at launch. The tip back takes some getting used to. By far, this is the easiest to get over the bump.”

Partic 13: “Kinda scary-tippy. It catches you off-guard until you’re comfortable with it.”

Partic 14: “ The drive wheels are harder (to push over the bump) than the Breezy.”
“ It feels like it turns and twists (when going over the bump). It’s an insecure feeling.”

DWR

1.1

Partic 5: “This feels slightly easier or about the same (as backing the Breezy’s drive wheels over the obstacle).

2.1

Partic 6: “One wheel slips and the other gets over before it.”

3.1

Partic 5: “It feels equal to a standard wheelchair.”

2.2

Partic 7: “(Drive wheel) slips sometimes on one side when traveling backward.

Backing casters over bump w/runup:

Q: This is a non-comparative question, how did it feel to go over the bump?

1.1

Partic 5: “It feels like the 2nd chair (1.2). (“Rough, but with a runup, I didn’t feel like I was going to fall over.”)

2.1:

Partic 12: “It’s a little rough, but seems more stable than a standard wheelchair.”

1.2

Partic 4: “Rough, but possible with a runup.”

Partic 5: “Rough, but with a runup, I didn’t feel like I was going to fall over.”

Partic 12: “It was about the same experience (as 2.1). Once I got used to the initial instability, I liked it better than the last.”

2.2

Partic 5: “It felt equal to others (1.2 and 1.1) . (“Rough, but with a runup, I didn’t feel like I was going to fall over.”)

Partic 12: “ This chair feels safer, more secure. It seems like the front casters hit hard (when backing up), however I liked this the most so far (more than 2.1 and 1.2).”

3.1

Partic 4: “It’s a ‘bumpety-bumpety’ road between the casters and the drive wheels when trying to get over the obstacle (w/a 6” runup).

Partic 5: “With a little momentum (3-6” runup), it’s easy to get over the bump.”

3.2

Partic 7: “I can get over (the obstacle) with a runup. It (the wheel) slipped slightly and pulled to one side.”

Partic 12: “The front casters slam a bit when going backwards. The slam gets less you after you get comfortable with the chair.”

Favorite:

2.1:

Partic 1: “2.1 was my favorite. It was the most stable of the chairs I tested”

Partic 4: “The first test chair (2.1) felt most sturdy. It moved well. Maybe it was not the easiest on bumps, but was most responsive.” “It didn’t want to pop-up at the slightest jerk (of the wheels when pushing forward).

Partic 8: “I liked the 2nd to last chair (2.1). It gets over the bump and has no wheelie problem or tipping problem.”

2.2:

Partic 3: “This is tough. There are not severe differences in this test. It’s a small obstacle. A larger obstacle may help to weed things out a bit. I pick this one (2.2).

Partic 5: “It’s easy to ‘pop’ over the obstacle and handles really well. It has better handling. It feels like it has a better turning radius (than the other wheelchairs).

Partic 13: “It’s easier to use and maneuver.”

Partic 15: “It’s just slightly harder to push over the obstacle. The feeling of instability is the best feeling (of all the test chairs).

3.1

Partic 2: “Others were sometimes too hard to push over the obstacle. This one had the fewest overall ‘cons.’ I didn’t have the perception that I would flip over. When that happened (on the other chairs) I didn’t like that.”

Partic 10: “It went over bumps nicely. It’s not as tippy, but offers some benefits in terms of ease of going over the obstacle.”

Partic 11: “The drive wheels feel like they’re in a good position for propulsion”

3.2

Partic 6: “I liked the softness of how it goes over bumps.”

Partic 7: “Except for not being able to back-up over an obstacle from a stop, I like this

chair the most. The instability is not that big a deal because the chair has stops. It would be better if you found a way to cushion the stops.” <Note: semi-skilled wheelchair user with excellent postural control.>

Breezy:

Partic 8: “ I like the Breezy better. Something feels more comfortable, softer.”

Least Favorite:

1.2

Partic 2: “It scared me going over (the obstacle). I had to compensate a lot with my abdomen (postural adjustments).”

Partic 5: “I like the ‘power lifting’ chair the least (1.2). I just want to roll-over stuff” <User suggested during DWF comments that peak force to get over obstacle felt high.>

Partic 8: “ I stay in a wheelie too much. I know that the (safety) stop is there, but going backwards is a awkward, rickety movement”

3.1

Partic 3: “Again, this is tough. I think that it was the first chair I tested (3.1). Check my scores.”

Partic 7: “Again, the ‘kickup’ (wheelchair pops a wheelie at launch) is disconcerting initially.”

3.2:

Partic 1: “Even without going over an obstacle, there is significant tilt. Of course, this is based on my expectations. The Breezy doesn’t do that.”

Partic 4: “This chair seemed generally precarious. Maybe 1.2 would be a better compromise if you wanted a chair that could go into a wheelie easily.”

Partic 10: “It’s very tippy.”

Partic 13: “ TIPPY!”

General Comments:

Partic1: “Are the (test) chairs heavier than the Breezy? They feel heavier than the Breezy.”

Partic1: “The armrests move around a lot.”

Partic1: “When I put the front casters over the obstacle, I wonder if the front casters were ‘latching’ forward. It feels as if there’s something spring-loaded, like shocks.”

Partic1: “The experimental chairs feel narrower (than the Breezy).” <I allowed user to compare the width of their test chair to the Breezy. They are identical in width.> “I guess it’s because the armrests “tuck-in” on the user more.”

Partic 1: “ The Breezy is tough competition, especially when considering a small obstacle.”

Partic 2: “This is tough to say, but I might like the Breezy best.”

Partic 3: “There is a definite difference between using a chair that has a solid and (one that has) a sling seat.”

Partic 4: “I want to reach back further on a standard WC. It expands my chest (user reaches back and arches his shoulders severely) and generates discomfort.

Partic 5: “(2.2) It handles really well. All the other chairs can’t spin like this.”

Partic 7: “(2.2) I like that I can flick the chair around and turn. It feels smooth and a lot more stable. I like the chair”

Partic 7: “(1.1) It doesn’t spin in a circle as easily (as the others).”

Partic 7: “ I still like the Breezy. It’s a good chair.” “I liked its smoothness and sense of stability.”

Partic 8: (Comment about config 2.2). “It feels like I’m sitting higher (than the other wheelchairs).”

Partic 14: “The Breezy, psychologically, makes me feel more secure.”

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